Models in Action

Realising Abstractions

Juhl, Joakim

Publication date:
2013

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):
Juhl, J. (2013). *Models in Action: Realising Abstractions*. Aalborg Universitetsforlag.

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PhD Thesis submitted April 2013

Aalborg University The Doctoral School of Engineering and Science

Centre for Design, Innovation and Sustainable Transition

Joakim Juhl

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Acknowledgements

Many people have contributed to this thesis in one way or another. First of all I want to thank my colleagues and good friends at DTU, CBS, RUC, and AAU: Hanne Lindegaard, Christian Clausen, Yutaka Yoshinaka, Ulrik Jørgensen, Anders Buch, Andrés Felipe Valdemarra Pineda, Søsser Brodersen, Erik Hagelskjær, Andreas Birkbak, Anna Rose Vagn Jensen, Anne Katrine Brogaard Harders, Bente Hessellund Andersen, Birgitte Hoffmann, Brian Vad Mathiesen, Charlotte Louise Jensen, Chiara Farné Fratini, Ditte Degnbol, Emil Urhammer, Ida Lise Jensen, Inge Røpke, Jens Stissing Jensen, John Holten-Andersen, Lars Ege Larsen, Lene Alsbjørn, Louise Brønnum, Maj-Britt Quitzau, Michael Søgaard Jørgensen, Morten Elle, Morten Krogh Petersen, Per Richard Hansen, Peter Karnøe, Peter Munthe-Kaas, Rikke Premer Petersen, Signe Pedersen, Sophie Nyborg, Susse Georg, Tanja Rosenqvist, Martin Gylling, Stig Andur, Pedersen, Muniza Rehman and Trine Hertz.

I also whish to use this opportunity to express my gratefulness for the insightful and competent feedback that I, throughout my study, have received from my two PhD supervisors: Torben Elgaard Jensen and Anders Kristian Munk. I owe a lot to our conversations and can honestly say that I consider them as my entry to the field of Science & Technology Studies.

Secondly, I want to thank Mikaela Sundberg for offering me valuable help and feedback and becoming a good friend during my stay at Stockholm University in 2012. I also want to thank all who became my friends at SU and made me feel utmost welcome and offered me valuable feedback on my work: Isabelle Andersson, Josefin Bernhardsson, Edvin Sandström, Ellinor Anderberg, Maria Brandén, Lina Eklund, Sara Roman, Sofi Ohlsson-Wijk, Jani Turunen, Ida Viklund, Kieron Barclay, Sara Kjellsson, Carl Sandberg, Moa Brusell, Lina Bäckstrand, Sunnee Billingsley and Petter Bengtsson.

I also want to thank all who contributed to the empirical part of my study. I greatly appreciate all the help that the participants in the regulation project have offered my project.

Especially during the last and painstaking part of my writing I want to thank my family and friends for their support and their patience.

Most of all, I whish to thank my beloved girl friend and life companion Sidsel Lumholtz, who has supported, encouraged and borne with me all along.

Chapter One

Introduction

Models in Action – realising abstractions

This thesis is about science and technology in a particular case of mathematical modelling for industrial production optimisation. The relationship between science and society has always been at the heart of Science and Technology Studies (Jasanoff, 1996). Previous studies on simulation models have however primarily focused on scientific contexts. As a societal agent, industry nonetheless performs an imperative role by materialising scientific re-presentations into society through distribution of technology. "Technology is society made durable" (Latour, 1991). By utilising and producing technology, we can understand industry to closely couple scientific knowledge outputs with economy, living standards, natural resources, and the global climate. Industry thereby plays a crucial role in building and maintaining our society, while also being a huge source of environmental problems. Mathematical modelling makes an especially interesting case in industrial development, because it both involves a special kind of knowledge practice, and a distinctive type of technology that entails a great variety of model-materialities that connect the different operational environments that are involved. This study thereby attempts to describe mathematical modelling as both a technology and a method that not only contributes to scientific knowledge production, but also connects science with other important parts of society. The aim is to redirect attention from primarily seeing mathematical models as knowledge devices in certain scientific practices, to see them as technological actors across science and society. Mathematical models can be seen as especially important in this view, because they not only provide conditions for new scientific knowledge, but also for co-production (Jasanoff, 2013) by machinating scientific knowledge into societal effects.

The purpose of this thesis is to describe how mathematical models are developed for the purpose of regulating industrial production processes. The empirical basis of the present thesis is a multi-sited ethnographical study of the cooperation between three private companies and two universities in Denmark. The project I immersed myself into lasted for two years and served the purpose of developing and testing new industrial regulation technology. This new technology was to incorporate representative mathematical modelling as part of new regulation models that could improve both the process quality, and the energy-efficiency of an industrial production. The project's official title was "Energy-effective regulation of separation processes" but I will refer to it as the "regulation project". Because the variation of the practices in the regulation project spanned from work with abstract physical theory to practical hands-on work with machines at operational production sites, one of the aims with this thesis is to capture how these diverse practices connected. My methodological approach for this was to closely follow how knowledge artefacts were transformed by, and distributed among, the project participants in the regulation project. The study is therefore structured as an investigation of two opposite processes that occurred simultaneously: the "abstraction" of production machinery into theoretical physics, and the "concretisation" of theories into production machinery. Mathematical models were especially interesting in this technology developing setup since they were a significant part of both the processes that abstracted machinery and the processes that concretised theory. Furthermore mathematical models can also be seen to have filled an important role by coordinating between these two oppositely directed epistemic processes. By closely following each stage in the case study, I seek to extend our comprehension of models' technological dimension by describing the different material states the models go through from machine to theory and back again to the machine. In order to draw together the broader impact produced by the industrial project I discuss its achievements as various displacement effect. Furthermore I use the identified displacement effects to discuss what we can learn from this particular case of modelling in terms of how we can better interpret its special context when comparing it to previous work on simulation models and interpretations of scientific practice.

A World of Models

Mathematical models are also typically referred to as simulation models. When people first hear about mathematical models, a common reaction is to think of highly complicated scientific work submerged in what to most seem like inaccessible mathematical formulas and equations. When the topic is portrayed by the entertainment industry, in TV-shows and movies, simulation models are typically presented in high-tech environments with colourful 3-dimensional virtual realities of otherwise hidden secrets. While these exotic depictions understandably are far from what most people have personally experienced, the reality of mathematical models is that they are far more involved with the way we live our daily lives, than what we tend to think or notice. One of the most obvious and illustrative examples of this is the weather forecasting that daily guides planning of our outdoor activities. Weather forecasting is strongly tied to the use of comprehensive mathematical modelling in order to process the continuous stream of incoming meteorological data (Sundberg, 2006). The graphical illustrations of moving cold- and warm fronts across our TV screens are visualised outputs from these weather forecasting models- such visual outputs are also called “simulations”. We can see the weather forecasting models as means for presenting weather systems. In that vein we can understand them as models that represents a target system and thereby as models *of* something. While weather models are located far from our homes and operated by people, whom we don’t know, there are many other kinds of models that we in our daily lives engage more directly with. If we for instance use a GPS device, we find that it also deploys a whole range of different models that support its functionality. First of all, it locates its own position by calculation. The GPS receiver can mathematically triangulate its position based on the location of and distance to at least three satellites. Another model based GPS function is the estimated time of arrival (ETA). This function is based on historical data and has both to predict an average speed and the remaining distance. We might also notice that some of our battery powered electronic devices indicate a remaining battery time. While such functionality may seem simple, the predictive calculation behind it can be rather complicated. Like the ETA calculation in a GPS device, prediction of battery time typically involves several estimations. It needs for example to predict the amount of useful power that remains on the battery. The expected power consumption is also necessary in order to produce a combined prediction. While these varieties of models can be seen to represent something like the weather models do, they can also be seen to serve operational purposes. –For instance regulating power consumption or predicting optimal routes. In this sense we can see these as models *for* something.

Embedded as an automated part of the operational functionality in a vast amount of the technology that we daily use, models have become increasingly instrumental to how we live. Integrated into the black-boxed functionality of the products we daily use, these operational models mostly remain hidden from our attention. It is only when something stops responding or behaving as we expect that this technology begin to draw attention to itself (Latour and Woolgar, 1979/1986). For instance when a GPS receiver cannot sufficiently access satellites and therefore fails to locate its position. Meanwhile we go about using our mobile phones, computers, cars, refrigerators, and microwave ovens in perfectly air conditioned environments –just to mention a few potential areas of implementation. Not all things are models of course. However defining what exactly qualifies as a model and what does not is out of this thesis’ scope as will be discussed shortly hereafter. For the time being a broad definition of the kind of models that this thesis concerns, can be delimitated to various kinds of operational units, which function in one way or another is influenced by mathematical scripts.

While we find that mathematical models are integral to the functionality of much of the equipment we use, we would find that almost every product that surrounds us has been subject to some form of mathematical modelling during it's production and distribution. Almost everywhere we look, mathematical models are either directly forming the world we live in, or shaping the ways we see it. From macro-scale economy and global warming to automated trading at trading floors and fuel-air mixture in our cars' engines, the rate of which mathematical modelling is disseminated and entangled with society augments the need for understanding modelling –both as a special kind of knowledge practice and as a rapidly developing and disseminating technology. While simulation models have predominantly been studied as knowledge objects in scientific practices, the notion of mathematical models entails a much broader affiliation with society than what can be assigned to scientific practice alone. Although science is seen to have an important relation to theory, hence also to models and more specifically to mathematical models (Dowling, 1999). The purpose of this study is instead to bring forth how models' materiality can be seen as inseparable from how models both can manipulate theoretical representations and the rest of the world. The focus on models' materiality however also emphasises their local embeddedness and the importance of understand them as part of particular surroundings. While models can be seen as supporting ways of producing knowledge about the world – as would be the framing of an epistemologist, we can also see models to produce a variety of effects in their different surroundings. This perspective turns away from philosophy of science to focus on the particularities and complex multiplicities that are associated with a pragmatic micro-process oriented sociology. I thus want to do as Latour (1987) suggests: to follow the models in the making. The intention with this thesis is thereby not to say something general about mathematical models. Instead the study concentrates on a particular case of mathematical modelling to produce a "thick" in-depth description that attempts to cover the full range of process-stages and material states of models that connect them to their various environments. The hope is that we through this perspective can achieve a better understanding of how modelling, in this particular case, produces a wide range of effects both in science and in other parts of society. This thesis' focus on the interplay between science- and technology development is therefore reflected in its title: "Models in Action – realising abstractions". This title draws inspiration from Bruno Latour's (1987) book "Science in Action" that is considered a milestone in the field of science and technology studies (Sismondo, 2012). It also comprises an important double meaning through the notion of "realising" by referring to the act of making abstractions as both bringing new things and new knowledge into being.

Models are what they do

As will later be discussed in the literature review on simulation models, much philosophical thought has been devoted to attempts on defining what "simulation models" are and more generally how we should understand the metaphysical concept of a "model". This study however, is dedicated to understanding what “mathematical models” can be made to do rather than attempting to contribute with fixed definitions of what models are. As I spelled out in the previous paragraph, mathematical models can take a great variety of shapes. Mathematical models that are programmed onto computers and have their output data projected through a graphical interphase are typically referred to as simulation models. The graphical outputs such models produce are called simulations. Because mathematical models and simulations are conducted on computers, the term “computer model” is also widely used. In the literature we thereby see an almost interchangeable use of the terms: “mathematical model”, “computer model”, and “simulation model”. While there are many things that could be said about how these terms can be seen differ, the simple point I intend to make is that the study presented in this thesis concerns the broader notion of “mathematical models” of which computerised models are just one material variant. Because simulation models entail a mathematical model and must be run on some form of computer platform, I will generally use the terms; mathematical model, simulation model, and computer model almost interchangeably – unless otherwise stated, and I have a specific point to make on the choice of notion. Since the purpose of this study is to explore and describe what different states of models we can see are engaged in a technology-developing project, where models connect a target system with theoretical physics, I maintain a pragmatic position regarding the definition of “models”. While one could attempt to metaphysically deduce what simulations and mathematical models “should be”, the purpose of this thesis is quite different. Instead this thesis seeks to empirically discover how models are constructed, what they do, and what performative effects they have on specific locations. This attention to the situated pragmatics of models also entail an interest in what kind of meanings that different models can be understood to produce in their environments. In a machine environment the effects of a regulation model are very different than the effects we can understand a conceptual sketch on a blackboard to produce. While these two examples of models are unquestionably very different, they are nevertheless both models, and may relate to an equally large degree on mathematics – however in quite different ways. My point is that any fixed a-priory definition would be at the risk of excluding something from my study, before I would be able to recognise whether or how it had significance to what I study. The outset of the study is therefore to remain agnostic regarding definitions (Callon, 1986) and instead follow how the actors through their actions of ascribing meaning to what I study (Latour, 2005). It is thereby through empirical descriptions that I seek to produce novel insight to what models can be, and how we can understand the full range of modelling in the particular case I have studied. A central goal of the thesis is therefore to produce an empirically informed account of the kind of context that the regulation project can be understood to operate within.

Models as Re-Presentational Matter

An important ontological point that this thesis is builds on, is that mathematical models and models must be understood as part of a material reality. No matter what they represent, they do so through material means. –Whether that be computerised algorithms or a few dashes of ink on a piece of paper, these materialities are at once important for how knowledge is presented, and important for how that knowledge can be shared, manipulated, and deployed for various ends. The position I adhere to is that knowledge objects are material and not just metaphysical concepts of the human mind. The important empirical and analytical advantage of this position is that we can study objects like models as things that people make, use, share, move, modify, interpret, reshape, and deploy together with other things. In other words we can learn something about how models are used by following them as different material entities that are transformed from one use in one context to another use in another context. We can thus see the transformations that models undergo to hold a great potential for understanding both what models are made to do –and how they are configured to do certain things. The material transformations are thereby central to decipher the performance of the models, whether they are drawings on a black board or integral operational circuitry in some of the technologies that surrounds us. The position I adhere to, in my study of models, is by no means new, and builds on what has become the tradition more broadly known as Science and Technology Studies, (STS), while also often referred to as Science, Technology and Society (S&TS). The origin of STS was closely tied to studies of scientific practice in laboratories (Knorr Cetina, 1995). An important methodological position of these laboratory studies was to pay as much analytical attention to humans as to things. The STS position thereby contrasted with previous work that can be identified as the "sociology of science" position associated with the work of Robert K. Merton. One of the means that was central to STS, in order to connect human action with material entities in the scientific game of knowledge production, was to tie scientific practice to their use of different kinds of material re-presentations. A reason for choosing the notion of "re-presentation" can partly be seen as an attempt to avoid mixing up the intended meaning of the STS term with that of the philosophical tradition of representationalism. The great advantage of "re-presentation" is that it avoids the metaphysical conflict proposed by the subject-object dichotomy, while at the same time defines material transformations as its study object. These material transformations can be traced and linked both to the people and the organisations, by which they are handled –and to the knowledge claims the re-presentations are made to support. While I will clarify what recognitions I draw from STS onto my study of models in the chapter on "Re-Presentations in Science and Technology", my attempt is here to form bridge between my interpretation of models as material artefacts and the STS notion of re-presentations. Phrased more directly, I suggest there is much to be gained by interpreting models as special variants of re-presentations.

A short note on Mathematics in relation to the rest of the World

Because this thesis is about mathematical models, which I interpret as a special kind of re-presentation of other parts of the world, I also want to make clear how I interpret the "mathematical" aspect of what I study. A great deal of Philosophical discussion since the ancient Greece, has dealt with the subject of how to understand what mathematics are. I have no intention to contribute to this great body of work, by trying to offer a new interpretation of how mathematics can be understood in general. I rather see mathematics as a part of what I study, and therefore as an inseparable part of the particular event that I try to understand. My position on mathematics is therefore pragmatic in the sense that I frame it broadly as a language that I see a human construct that consistently undergoes transformations through how it is used. Mathematics does however have some performative features that make it special. What makes mathematics particularly special is that it has been defined and built on a closed logic system within which it has been designed to be as concise and precise as possible. Mathematics is a language that thereby can be seen to support complex manipulations and computations through traceable processes that offer a high degree of reversibility. The great precision of mathematics is however both its advantage and its Achilles heel –unless one believes that mathematics belongs to a superhuman domain as was implied by Galileo (1623) in the Assayer:

"Philosophy [nature] is written in that great book which ever is before our eyes -- I mean the universe -- but we cannot understand it if we do not first learn the language and grasp the symbols in which it is written. The book is written in mathematical language, and the symbols are triangles, circles and other geometrical figures, without whose help it is impossible to comprehend a single word of it; without which one wanders in vain through a dark labyrinth."

My position is instead to see mathematics as a human construct with which we constantly try to make approximations, in order to grasp and manage the rest of the world. This is not an attempt to point out mathematics' insufficiencies. Instead my point is that a great deal of the challenge bound to the use of mathematics –on the rest of the world, lies in how both the world and mathematics are transformed in order to present an adequately compatible fit for its particular use applications. It is how this fit between the world and language is sought, of which the mathematical re-presentations, i.e. the models I study in this thesis, are an example. My interest is however not to make any judgements on how well these fits are made. Rather my interest lies in spelling out a way to understandinging what performative effects that are realised by making such fits. This concerns both how we can better comprehend the epistemic processes that were at play in the particular project I have studied, and how these fits were realised into wider effects in the environments, where they were implemented as technological solutions.

Structure of the Thesis

I will shortly present how I have structured this thesis. While I have sought to structure my arguments into chapters and sections, my intent has also been to present my work as a journey where the reader can follow my reasoning through the succession of the chapters and the sections.

Because of the empirical nature of the thesis my structure starts by spelling out the theoretical and methodological resources on which I draw to conduct my study. This section is made of chapter 2 where I present my broader literature review on how I build on recognitions form STS and the notion of re-presentations. Chapter 3 on the other hand presents a more focused review on the literature that specifically discusses mathematical modelling.

The next section presents my empirical study. Chapter 4 makes a short introduction to how the research idea behind the study came to be, and unfolds how this idea became the ethnographically informed research project presented in this thesis. Chapter 5 takes us to the factory, from which the project I have studied extracted information, and which they used as a case for developing and implementing automated regulation solutions. Chapter 6 follows closely how the information extracted from the factory is made to combine with physical theories in order to produce representative mathematical models. Chapter 7 traces how a regulation model is implemented back into a particular production environment.

The last section of the thesis rounds up and draws together the recognitions from the preceding chapters. Chapter 8 is a discussion of how the regulation project can be seen to have produced a variety of displacement effects in the production environment of the factory. Chapter 9 is a more focussed discussion on how we can understand the regulation project as a special case of modelling, and what we can learn form it, in terms of how it deviates from previous understandings of scientific practice. Chapter 10 presents the conclusion that draws together and summarises what we have learned form the regulation project empirically and theoretically.

Chapter Two

Re-Presentations in Science and Technology

Theoretical Outset for Studying Simulation Modelling

To study the practice of mathematical modelling there is no getting around its strong scientific heritage and relation to scientific practice. As we will see in the literature review on simulation models in chapter three, the predominant focus has been on models' roles in science. My empirical case study on simulation modelling is however not limited to simulation models in scientific contexts and is characterised by both concerning scientific practice and technology development. It is therefore central that my theoretical and methodological approach is applicable to both study how simulation models operate in a scientific context and in technology development, as well as how they crisscross between the two. For this purpose this thesis draws on the pragmatic Actor-Network Theoretical tradition (Callon, 1986; Latour, 1987; Law, 1992). ANT has since the late 80's developed to become a strong and widely deployed position within STS. ANT originated from the laboratory studies (Latour and Woolgar, 1979/1986) as a response to what its authors saw as a human-centric focus that was deployed in sociology of science – e.g. Bloor's (1976) so called Strong Program. From an ANT perspective accounting for science, or for that matter any other human activity, as social relations and -organisation had the deficiency of overlooking the important role of things' agency. According to ANT, humans and non-humans are associated with one another in heterogeneous Actor-Network formations. By defining everything as networks – things, humans, science, nature and society are seen to constantly negotiate, shape and re-shape each other by displacing and maintaining relations. A central interpretative principle of ANT was therefore to introduce both humans and non-humans as "actors" that are granted agency. ANT thereby proposes a style of thought that is agnostic about the distinction between humans and nonhumans. In this sense ANT allows things like simulation models to enter the centre stage of the analysis together with the human modellers who develop and use the models. This position gave rise to much resistance from proponents of sociology of scientific knowledge (e.g. Collins & Yearley, 1992) who argued, that the distinction between entities as being purely social or purely natural should be maintained. Their main point of these critics is that if social scientists take material agency seriously, their analytical authority would be handed over to natural scientists because they have the apparatus to define material agency. Callon and Latour's (1992) response to Collins and Yearly's argument is that it suggests us to switch between natural- and social realism depending on whether we are natural- or social scientists. Callon and Latour thereby maintain the position that both humans and things belong in the analysis of science if we are to avoid the problematic dichotomies of human-thing, subject-object and nature-society that Latour termed the modernist settlement (Latour, 1991/93). The ANT perspective therefore recognises 'social entities' as part of what is to be explained, rather then doing the explaining. My perspective is that social relations and -organisations are some of the interesting aspects of the events that I seek to account for in my analysis. Social constellations, can in this view, be seen as hybrid assemblages that are equally constituted by human actors, and the things as well as shared routines. I thereby see groups, such as scientific disciplines not as social groups, but as hybrid groups defined by how social actors share relations through things –i.e. theoretical re-presentations and other methodological instruments. In this line of thinking it is the tools, methods and experiences that e.g. theoretical physicists can be found to share, that manifests their relations as a group. When people who bear on different experiences, tools and methods work together, the same material artefacts – such as a visual re-presentation can, when shared, be seen to enter into different networks of relations, where they produce different meanings and effects. The meanings that can be ascribed to things like computer models therefore depend on the particular environments they are used in.

Simulation Models as Re-Presentations in Science, Technology and Society

When discussing simulation models, the notion of re-presentation is an inseparable element of their agency. Simulation models' outputs can be seen as forms of re-presentations –whether they are of visual, numerical, or analytical in character. Even the mathematical and theoretical structure of a simulation model can be perceived as a re-presentation of its target system. One of the reason for why I choose to interpret simulation models as a special kind of re-presentations, is that we gain the ability to discuss them in much broader terms due to the vast bulk of work there exists on re-presentations from studies on scientific practices and engineering. This enables us to make broader theoretical- and methodological resources relevant to the discussion of simulation models. We will therefore now first turn our lens to how the role of re-presentations has been construed in scientific practice. Later in chapter three, we will engage in a more focused discussion on simulation models that builds on literature that more narrowly treats the subject of simulation models, and how we understand their characteristic features.

The dedicated focus on the role of things in scientific practice was as mentioned an integral part of what became the ANT tradition. One of the central roles of things in scientific practice has been described as "re-presentations" among many scholars of science and technology studies (e.g. Jasanoff, 2004; Latour, 1987). In science and technology studies re-presentations has since the laboratory studies of Latour and Woolgar (1979/1986) been at the heart of understanding scientific practices. Based on anthropological field observations of how scientists conducted their work in laboratory environments, Latour and Woolgar has described the production and use of various visual and written re-presentations. The pioneering Laboratory Study showed re-presentations as integral to how the scientists work. In opposition to, the aforementioned ruling, human-centric perspective on science stemming from prominent sociologists of science like Thomas Kuhn (1962/2012), STS argues for the importance of the material settings and the central role of things such as re-presentations in understanding scientific practices. This emphasis on re-presentations in the analysis of scientific practice has a strong connection to the development of actor-network theory and the principle of generalized symmetry (Callon, 1986; Latour, 1987; Law, 1992) that addressed the aforementioned dichotomies of the modernist settlement (Latour, 1991/1993). The principle of generalized symmetry can be seen as ANT´s response to Bloor's (1976) Strong Program, which he again formulated as a reaction to the traditional division of labour between sociology of science and philosophy of science. The Strong Program included four central tenets; causality, impartiality, reflexivity, and lastly the symmetry principle. While Bloor's symmetry principle holds that the same type of cause should explain both true and false beliefs, the generalised symmetry principle of ANT rejects all dichotomies –including to Bloor's true-false dichotomy, those of humans-things and nature-society. Pels (1996) has argued that the difference between Bloor's symmetry and generalised symmetry can be expressed as the difference between epistemological and ontological symmetry. While Bloor's symmetry principle can be seen as an epistemological premise by telling us to use the same causes for explaining true and false beliefs, ANT's generalised symmetry principle can instead be seen as an ontological premise, because it rejects all a priori distinctions between entities. For Latour the rejection of this distinction is a part of his broader discussion of the so-called modernist settlement, Latour (1991/1993). He argues that the creation of problematic dichotomies is a direct result of a misunderstood purification project that was started by the idea of separating nature from society, things from humans, and objects from subjects. In Latour's perspective it is the modern Western invention of such dichotomies that has sealed off into incommensurable problems what different scientific disciplines and professions try to solve separately. According to Latour, the epistemological question of how we can know the outside world, the psychological question of how a mind can maintain a connection with an outside world, the political question of how wee can keep order in society, and the moral question of how we can live a good life must to be tackled all at once. By claiming that "we have never been modern" and proposing what he calls a non-modern approach, Latour extended the symmetry principle to epistemology, ontology, politics, and religion (Latour, 1991/1993). While sociology of scientific knowledge, and sociological perspectives more generally including social world theory, are symmetrical according to Bloor's (1976) definition, they are asymmetrical in the view of generalised symmetry (Callon and Latour, 1992). The fundamental difference is that the rationale behind the ANT-perspective, opposed to Bloor´s Strong Program, understands differences between human and nonhuman entities as generated in their network of relations and therefore should not be presupposed as given 'types of things'. Humans and nonhuman are actors that should be empirically and analytically treated equally. The implication of this rationale is to see scientists, modellers, and engineers and their nonhuman re-presentations as equally important to understanding an event. A further implication would be to resist the idea that 'the underlying physics' can predict the outcome of developing and implementing a model. In line with this reasoning Latour's (1987) third rule of method tells us that "[s]ince the settlement of a controversy is the *cause* of Nature's representation, not its consequence, we can never use this consequence, Nature, to explain how and why a controversy has been settled." (p. 258). In other words, we can neither assume that simulation models' 'underlying physics' is a "natural" consequence of Nature, nor that the underlying physics explain how and why models generate effects in their surroundings. The controversies that settle what underlying physics that is chosen to govern a model, is therefore as much to be explained, as the way the model is made to affect these controversies. In order to understand the broader range of models' performances, we therefore need to study both how socio-material controversies, such as a factory's operation, are settled into models, and how these models are made to displace that factory's operation. The underlying physics has never just been lying around waiting for someone to discover them, neither will they suddenly and all by themselves settle any socio-material controversies. The model construction can in this vein be seen as a specific type of purification project (Latour, 1991/1993) that seeks extract certain features from the factory, in order to manipulate them, so that they can generate certain intended effects when returned to the factory. We can however neither see the extraction of these features, nor the effects they through implementation are made to generate, as consequences of nature. In order to understand the modelling practices and their effects, we therefore have to pay attention to all the socio-material relations that are part of both the "upstream" extraction and the "downstream" implementation of models.

The attention to re-presentations as nonhuman actors that are integral to work practices thus introduced a perspective that both illuminated the discipline-specific- and inter-disciplinary roles of representations as things that transfer and transform knowledge through cascades of transformations (Latour, 1999). Representations are in this sense not only important to understand scientific work, but also to understand the diffusion of scientific knowledge into the rest of society (Jasanoff, 1996, 2004). An important outcome of STS´s heritage from ANT was the recognition that epistemological, political, sociological, and professional questions merged into one question. The answer to which was to be found in understanding the practices that build on and are tied together by representations. To understand how models operate and what is so special about them can thereby be seen as closely linked to understanding how they as mediators crisscross dichotomises such as thing-human, nature-society, and object-subject in science and technology. For instance how can we understand models to generate new connections between people, things, knowledge, science, and society?

Science and technology studies can hereby be seen to contribute by situating representations as integral to the practices that produce them, build on them, and reproduce them, by providing methodologies and a ranges of methods for studying and learning from these particular practices. STS thereby offers a range of empirical approaches that guide research on science and society by focusing on the important heterogeneous and complex relationships between humans and things to better understand what actors do. In Latour's (2005) formulation of his "practical metaphysics", he calls real and places "ontological weight" on anything an actor claims as source of motivation for action. I hereby see Latour to propose a methodological approach that involves a strong dedication to relativism by learning actor's language and record what they say about what they do. In Latour's practical metaphysics there is no "basic structure of reality" or single self-consistent world. The task of a researcher is therefore not to find one higher "basic structure" that supposedly explains actors' agency, but to recognise "the metaphysical innovations proposed by ordinary actors" (Latour, 2005). To cope with the metaphysical multiplicity of actors, Latour's metaphysical system contradicts traditional philosophical metaphysics by allowing the existence of an unknowable large multiplicity of realities and worlds. The project of Latour's empirical metaphysics is thus opposite to the traditional metaphysical project that attempts to define *the* basic structure of the world. Instead Latour suggests researchers to deal with "what the controversies over agencies lead to" (Latour, 2005) to explore the actor's own metaphysics through empiricism. Following Latour's perspective, my role as a researcher is to explore and document the metaphysical innovations that modellers produce when bringing simulation models into being.

When it comes to critique, Latour's empiricism is criticised for being too descriptive and sidestepping regarding political issues in simply documenting actor's multiplicity of metaphysics (Jasanoff, 2004). In the article: "Why Has Critique Run Out of Steam?" (Latour, 2004) Latour directly addressed social critique himself. Latour's critique of his own field, and social critique in general, is that it as currently practiced borders irrelevancy. He suggests that about 90 % of contemporary social criticism falls under one of two approaches that he terms “the fact position” and “the fairy position” (p. 237). The fact position he calls anti-fetishist and argues that objects of belief such as arts and religion are merely concepts onto which power is projected. The fairy position on the other hand argues that individuals are dominated, often covertly and without their awareness, by external forces such as economy and gender. Latour’s point is that no matter which position social critics takes they are always right. By picking and choosing their positions against ideas that they personally reject, social critics tend to show inconsistency and double-standards that have been largely unrecognised in social critique because there has never been a crossover between the two lists of objects used by either position (p. 241). Latour can thus be understood to readdresses the generalised symmetry position onto social critique by pointing out how it still constructs a divide between the fact and the fairy position. To remain credible and focused, Latour argues that social critique must insist on “cultivation of a stubbornly realist attitude -- to speak like William James” (Latour, 2004 p. 233). Latour thus argues that social researchers should embrace a realist attitude in their empiricism that shifts focus from an unrepentant and purely “matters of fact” based critique onto a critique that embraces the “matters of concern” of what we study. The implication of this way of thinking critique to the study of simulation models is that it articulates a contra-position to the otherwise strong focus on validation and justification of theories among epistemologists. An implication of this matter of concern driven critique would be to rather focus on what is at stake in the modellers’ work and what concern they can be understood to contribute. This can be seen as a stark non-representationalist alternative to laying judgement on whether, or to what degree, modellers in their theory articulation achieves representational rigour or mirror-like correspondence in a philosophical representationalist view (Knuttilla and Voutilainen, 2003).

Re-Presentations as Thing-Sign Vehicles – an Alternative Epistemology

This leads me to the philosophical basis of this thesis’ perspective on simulation models and re-presentations. Building on Latour’s (1999) empirical philosophy of what he terms “circulating reference” I take a radically different approach to the conception of simulation models’ representational value than that of philosophical representationalism. Representationalsim is a philosophical tradition that dates back to Platonism and takes Descartes’ object-subject divide as outset for its conception of knowledge and epistemology. To distinguish between the representationalist’ metaphysical conception of “representation” and the ANT-tradition’s pragmatic perspective on representations’ performances as both things and signs, I use the STS notion of “re-presentation”. Latour’s circulating reference describes scientific practice as the building of long cascades of references. Latour’s view thereby contrasts that of Descartes, that sees science as being the construction of thin and risky correspondence between the world and the mind as two separate domains (Latour, 1999). The fundamental difference between the views of Descartes and Latour on science is that Descartes builds on the ontological premise of separate domains for things and thoughts, whereas Latour provides an interpretation of things and thoughts as inseparable from each other. The epistemological difference between these two views, is that Descartes take two finite end points as the origin for interpretation; that of the "real world" phenomenon on one side – and on the other side, the representation of that phenomenon inside the "human mind". Latour however, investigates the phenomenon of scientific practice as building cascades of matter into form translations. Each translation of matter into form is understood to produce reference by means of generating "hybrids" –that are at once material things and signs for interpretation. Instead of operating from either sides of giant metaphysical gap –as proposed by Descartes, Latour proposes that scientific practice manipulates both the world and language at once. In this vein Latour argues that science rather works from "the middle" than from metaphysically separated extremes. Latour's interpretation of science is therefore a phenomenon that is practiced by extending its re-presentational reality both further towards locality, particularity, and materiality in one direction and further towards purification, abstraction, and circulation in the other direction. According to Latour, scientific reference is thereby about maintaining reversibility of all matter into form translations to ensure that they are connected and equally re-presents the phenomenon under study. In contrast to Descartes' idea of two separated and fixed ontological extremes, Latour recognises that scientific practice operates by extending towards the two potentially infinitely expanding extremes –of particular, local, and material complex re-presentations in one direction –and abstracted, aggregated, and generalised re-presentations in the other direction. Latour's perspective on the phenomenon of science is that it operates through the construction and maintenance of scientific references between all the intermediate re-presentations. He thereby identifies a common operator that belongs to matter at one end and to form at the other end. According to Latour, what is characteristic about scientific practice is that scientific reference enables the movement back and forth between all the intermediate steps of scientific practice. Each intermediate step re-represents the phenomena. Stage by stage the re-presentations have through reduction lost locality, particularity, materiality, multiplicity, and continuity. At the same time, at each step, the re-presentations have been amplified by gaining greater compatibility, standardisation, text, calculation, circulation, and relative universality.

By re-representing science as a human activity that operates by manipulating matter, Latour converts the philosophical questions of scientific epistemology and truth-value to be a practical question about how an event is manifested through hybrid things that works as sign-vehicles. Epistemological questions such as truth-value is thereby directed to circulate along the various material states of re-presentations that document an event. In Latour´s perception the meaning of science is to constantly distribute the abyss that separates things and words into many smaller gaps. The point is to maintain the traceability of data with minimal deformation while ridding the data from their local context by transforming them so that they can stand the travel from their original locality to another. Through all the transformations, it is the *meaning* that is kept, not the "representational" resemblance. The explanation that Latour's anthropology of science demonstrates is that it is through the transformation and manipulation of matter, that things are made into signs, or inscriptions as Latour also terms them. Inscriptions refer to "all the types of transformations through which an entity becomes materialized into a sign, an archive, a document, a piece of paper, a trace" (Latour, 1999). The point is that by distributing the abyss between world and language into many smaller gaps –between things and signs, both the world and language is transformed in order to become compatible.

In formulating his empirical philosophy on scientific reference, Latour criticises analytical philosophy for having been too preoccupied with the idea of transforming language to speak of the world. – For having a much more discriminating vocabulary for speaking of discourse itself rather than for how things engage into discourse. The central point is that analytical philosophy in its quest for "discovering how we can speak of the world in a language capable of truth" (p. 48), has neglected how the world is transformed to comply with language. The important recognition that I draw from Latour is how much the world typically must be manipulated and transformed in order to apply to human language such as mathematics in the case of simulation modelling. As Latour (1999) says: "For the world to become knowable, it must become a laboratory" (p. 43). With Latour's field expedition as an example I seek to approach mathematical modelling by examining how "all the empty forms are setup *behind* the phenomena *before* the phenomena manifests themselves, *in order* for them to be manifested." (Latour, p. 49). In other words, how and with what forms do the modellers manifest their targets system as mathematical models?

The major advantage of Latour's view over the subject-object dichotomy is that Latour's concept of circulating reference enables us to see each representation in the long cascades of scientific references as equally material, important, and real as the event that they re-represents. Models and representations thus afford actual presence to phenomena in collaborative and cognitive practices, whether that is in natural science or in professional engineering practices. In this perspective, each representation is both a result of the previous process and the basis and working condition for the process to follow. This philosophical principle stresses an understanding that representations not only communicate recognitions, but also materialize, preserve, and facilitate the intermediate steps in knowledge production.

Re-Presentations and Knowledge Accumulation

The practice of collecting empirical observations and making them combinable and able to travel across space and time was described in "Visualization and Cognition: Drawing Things Together" (Latour, 1983). Here, Latour builds on Eisenstein's explanation of how the Danish astronomer Tycho Brahe was able to make his great discoveries. According to Eisenstein, Brahe made his discoveries not because he was physically closer than his predecessors to the phenomena he observed, but because he was one of the first to have access to all observations and predictions made by his predecessors, in a language or code he mastered and collected in the same place:

"It was not because he gazed at night skies instead of at old books that Tycho Brahe differed from stargazers of the past. Nor do I think it was because he cared more for "stubborn facts" and precise measurement than had the Alexandrians or the Arabs. But he did have at his disposal, as few had before him, two separate sets of computations based on two different theories, compiled several centuries apart which he could compare with each other." (Eisenstein, 1979, p. 624)

The point that Latour bases on Eisenstein's work – and which I apply as an interpretative principle on the modelling activities – is the generative effect of creating and collecting visual re-presentations in cognition and epistemology. While preserving and accumulating observations and ideas are seen as a central principle in the realisation of many great discoveries throughout history, I find that the same interpretative principle is relevant to the small-scale discoveries realised by the mathematical modellers and regulation technology developers.

The preserving ability of representations that enables the inscriptions they contain, to travel across space and time, is also central to the re-presentations we observe in modelling. By drawing how they comprehend industrial machines, modellers capture and preserve their observations on paper or display them on boards in their offices or meeting rooms. With the notion of "immutable mobiles" (Latour, 1983) emphasizes the ability and role of visual representations to be carriers that make experiences and knowledge durable across space and time, and thus to facilitate epistemic processes. On a smaller scale, the role of the re-presentations that we observe in the modellers' model creation process facilitates their ability to produce and combine inscriptions through drawings.

Another important notion of Latour is "centres of calculation" that are any site where inscriptions are combined and make possible a type of calculation

(Latorur 1987). Such sites can be a laboratory, a statistical institution, the files of a geographer, a data bank, and so forth. Centres of calculations locate in specific sites an ability that is too often placed in the mind. It is an important trait of mathematical models that they can form and operate as sites of calculation. But as empirical examples of centres of calculation, the more interesting question is how mathematical models become such sites.

Re-Presentations in Symbolic Interactionism and Social Worlds Theory

From the early 1990s, interest in representations expanded within engineering studies and engineering design research (Bucciarelli, 1994; Henderson, 1991, 1995, 1999; Carlile, 2002). Within engineering, the role of representations became strongly linked to collaborative challenges between different engineering disciplines in engineering design.

Based on ethnographic methods, STS has approached professional practices by following the transformation of documentation as it moved around in organisational settings such as those at Boeing, BP, CISCO, Ford, IBM, NASA, and Statoil (Henderson, 1991, 1995, 1999; Carlile, 2002).

Engineering studies that build on symbolic interactionism and social world theory has since the 1990s pointed out that the highly specialized knowledge in the professions they studied was strongly linked to the visual representations that the practitioners worked with. The studies also showed these representations to be highly codified and specific to the practice they were used in (Star & Griesemer, 1989). The specific codification in each profession thus contributed to the inaccessibility of their representations for practitioners outside their practice (Bucciarelli, 1994). In *Designing Engineers*, Bucciarelli (1994) develops the term object worlds to describe how engineers see and reason through the material objects that surround their professional practice. He describes, for instance, how a specialist working with solar cells reads the path of the sun over the sky by using a curved graph that relates current and voltage during a cloudless day. Along the same line of thinking, the modellers can be seen to build around them their specialized world, inhabited by sketches, drawings, and notes, which relate them to what they model.

Henderson (1991, 1995, 1999) and later Carlile (2002) both recognized the mediating ability of certain visual representations as carriers of codified knowledge across different knowledge domains. Henderson termed the ability of these visual representations "meta-indexicality" because they "serve as meeting ground for different kinds of knowledge" (Henderson, 1999). Meta-indexicality is, according to Henderson, the ability of visual representations to combine many diverse levels of knowledge and thereby serve as a meeting ground for many types of practitioners. To Henderson meta-indexicality refers both to the ability of visual representations to contain different levels and types of codified knowledge and to the collaborative role of visual representations to enable practitioners to meet and negotiate their different kinds of knowledge.

Carlile focused on knowledge transfer between different disciplinary practices facilitated through material objects, for which he used the notion “boundary objects” drawing on Star and Griesemer (1989). For Star and Griesemer, boundary objects are shared and shareable across problem-solving disciplines, where they work to establish a shared context that “sits in the middle” (Star, 1989). In adapting the boundary object concept, Carlile focused on the characteristics that make them effective across what he introduce as syntactic, semantic, and pragmatic knowledge boundaries (Carlile, 2002). He argued that “first, a boundary object establishes a shared syntax or language for individuals to present their knowledge” (p. 451). In design and innovation, Carlile argued that a syntactic knowledge transfer is insufficient to handle the novelty that arises at the more complex knowledge boundary. This boundary is overcome, when as Carlile stated, “an effective boundary object at a semantic boundary provides a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary” (p. 452). According to Carlile, these differences and dependencies often result in negative consequences that must be resolved. These negative consequences are resolved when, according to Carlile, “at a pragmatic boundary an effective boundary object facilitates a process where individuals can jointly transform their knowledge” (p. 452). A negative consequence can occur when involved practitioners alter, negotiate, or change their hard-won knowledge by, for instance, changing the object or representation used –and thereby the material state of their knowledge.

Mathematical Modelling as Distributed Cognition

In this paragraph we will look at visual representations in the perspective of materially- and culturally distributed cognition. Descriptions like the following quote from Henderson’s book “On-line and on paper” illustrate the kind of recognitions that a situated perspective on modelling can gain from engineering design:

“The visual culture of engineering is one in which people turn to drawings when asked a design question, like the member of a NASA research and design team who was told “better go get the drawings” when he tried to describe a part using gestures and an adding-machine tape. It is more than the collaborative visual thinking of two engineers, so deep in discussion of modifications to their surgical instrument design that they sketch together, using one pad of paper and one writing implement, unconsciously passing the pencil back and forth with a coordination suggesting one mind instead of two. The visual culture of engineering is more than the sum of its parts: the practices of sketching and drawing constitute communication in the design world." (Henderson, 1999, p. 25)

While Henderson beautifully depicts how visual language is central in realising engineering design, I seek to understand how the visual culture of modellers constitutes "one mind". We can see the collaborative effort of drawing visual representations together as what Hutchins call distributed cognition (1995). If for instance individuals share inscriptions on the same surface they can be observed to jointly transform their visual representations and thereby their interpretation of what they work with. Including inscriptions that carry different types of knowledge, such as mechanical drawings and mathematical functions, such visual representations can be understood to gain what Henderson call meta-indexicality. The idea is that observations on visual practice thereby can provide an empirical access to how modellers and other practitioners "distribute" cognition in their surroundings. This perspective stems from Hutchins' (1995) ethnographic work on what he calls naturally situated and culturally distributed cognition. Drawing on the anthropological tradition Hutchins made a significant contribution to cognitive psychology by proposing an interpretative framework that avoids the mind-world dichotomy. Hutchins' work hereby offers an analytical framework to understand cognitive processes that aligns with the principles of ANT's generalised symmetry (Latour, 1996). The theoretical and epistemological basis for the exploration and interpretation of models and representations is the idea that cognition is distributed and situated in the settings where people and things produce and reproduce recognitions. From this perspective, the notion of cognition is therefore inseparable from the things through which we produce recognitions such as re-presentations. Therefore realising is a phenomenon that is equally mental, material, and social. This idea of cognition builds on the underlying ontological principle that recognitions are embedded into their particular local, historical, and social settings. Opposed to the positivist and post positivist ideal of true recognitions, which are generalizable and therefore freed from the historical and local settings and practices that produce them, this epistemological premise claims that recognitions are realised and empowered through historical, local, social, and material practices (Latour, 1988). Inspired by Hutchins and Latour, I approach re-presentations as integral to distributed cognitive processes in modelling.

As briefly discussed above, representations have been described as a meeting ground for diverse levels of knowledge and practitioners (Henderson, 1999) and in their role as boundary objects in facilitating knowledge transfer across disciplines (Carlile, 2002). By closely studying the representations that are used to realise the regulation project, this thesis deploys an ethnographic case study to gain insight to the generation of representations and their role in a collaborative modelling and technology development. This thesis thus aims on contributing to the understanding of simulation modelling with a detailed understanding of the particular social and material circumstances under which representations are produced as part of modelling.

Chapter Three

Existing Literature on Simulation Models

Discussions on Simulation Models in STS and Philosophy of Science

As mentioned in the introduction, the majority of available literature on the topic of mathematical models and simulation models treats models as knowledge objects in scientific practice. This focus appears to have been adopted from philosophy of science where most epistemological thought historically has concerned how we understand theory (Johnson, 2006). Consequently, when philosophy of science began to develop an interest for scientific simulation models, the dominant idea that science was about theory, got projected onto mathematical models (e.g. Dowling, 1999). However, a more recent position within philosophy of science argues that because experiments make up the majority of scientific activity, it is experiment that constitutes the meat of science (Hacking, 1983; Franklin, 1989).

These conflicting positions have thereby born simulation models into a continually lively and unsettled debate on what constitutes science. Characterised by the historical and territorial theory-experiment split (Rohrlich, 1990; Winsberg, 2003) the discussion on simulation models is thus inherited form the long-lived divide between epistemologists who still fight about whether experiment or theory constitutes the meat of science. The propositions are consequently whether models and simulations belong to the conceptual domain of theory, or are part of the material domain of experiment. In other words, are models and simulations part of theoretical reasoning or do they produce experimental knowledge about the world? The on-going discussion on what simulations and mathematical models are, and how they can be understood to support knowledge production, must therefore be understood to relate far beyond the field of simulations and models, and concern broader discussion on the "essence" of science as a whole.

I see the experiment-theory split as one of the major axes of discussion in the simulation modelling literature. Authors in favour of seeing mathematical models and simulations as experimentation (Galison, 1996; Dowling, 1999; Keller 2003; Morgan 2003) argue that computer simulations and models are experiments on theories. This position sees simulations as a kind of virtual experiments that produce new data and claim that simulations and mathematical models belong to the category of experimentation (Humphreys, 2004). On the other side, the semantic position on theories construe models and simulations as theory based on the view that theories are comprised of a class of models and that simulations are computer-enhanced models (Sismondo, 1999; Dowling, 1999). Authors in support of this position (Winsberg, 2009; Petersen, 2012) have more recently argued that simulations and experiments are strictly different due to that simulations involve `mathematical objects´, while experiments involve `material objects´, and that they require different sets of skills. In response to this, it is argued that computer simulations should be seen as material experiments because they involve manipulation and observation of behaviour in computer systems, which after all are physical systems (Parker, 2009). This argument is contrasted by the view that simulations deploy models to study objects whereas experiments concern the very objects of study (Gilbert and Troitzsch, 2005). Barberousse et al. (2009) propose that the reason for why and how computer models and simulations produce information about their target systems, needs to be found through semantic analysis of how physical computers´ successive computational stages, stepwise become values of variables and finally representations of their target systems. However the fact that computer processing is a physical process does not alone sufficiently explain the relationship between computer models and their target systems. The core of this line of arguments against seeing simulation models as experiments is based on the idea that experiments rely on "direct" material correspondence with their target systems, while simulation models' correspondence with their target systems is supposed to be strictly formal (Guala, 2005). They key point is that mathematical models and simulations are assumed to share no material connection with what they represent, and therefore must belong to the domain of theoretical reasoning. A viewpoint that has pronounced support among natural scientists who see models and simulations as theory. Simulation scientists typically claim that their work is theoretical, and experimental scientists and instrument designers claim that simulations have little or nothing to do with neither the "real world" nor even science (Baird, 2005). The central points on each side of the theory-experiment trench, are that simulation models in fact do produce new data in favour of the experiment- position, but that they do so without material correspondence with their target system in favour of the theory-position.

The tension between these two views on models and simulations as either an extension of theory or experiment, has lead to a third position that sees models and simulations as an intermediates or hybrids between theory and experiment. This position claims that models and simulations constitute a new mode in scientific knowledge production that shares similarities with both theory and experiment, but is not reducible to either. This position has become widely accepted in STS and is becoming increasingly common (Galison, 1996; Dowling, 1999; Winsberg, 2003). While this third position seems more realistic because it makes room for models and simulations' similarities to both theory and experiment, it does not attempt to explain what mathematical models and simulations are, nor the problem of how their mathematical structure relates to their target systems. Sismondo (1999) described mathematical models and simulations as occupying an uneasy space between theory and experiment, where they can connect theory with data and make more exact predictions than theories can. Merz (1999), Sundberg, (2006,2007,2009;) and Johnson, (2006) demonstrate this position through how experimental scientific work in particle physics, meteorology, and nanotechnology respectively, is strongly tied to mathematical modelling and simulation. Mathematical models and simulations are used as part of shaping and planning experimental setups (Merz, 1999; Sundberg, 2006; Johnson, 2006), and are institutionally closely coupled humanly, financially, and computationally with experimental setups (Johnson, 2006). STS thus renders how models and simulations are embedded in social, financial, computational, and institutional scientific surroundings. This offers a more complete picture of how modelling- and simulation practices are socially, financially, organisationally, and epistemologically distributed and play an important role in how knowledge and data are connected with theory in current modes of scientific reasoning- and experimental practices. The important implication of the practice oriented STS-perspectives are that they contribute by situating simulation models and their construction processes as part of the lived messy world. Knuuttila and Voutilainen (2003) add to this multiplicity-oriented position the epistemic importance of scientific model´s materiality. Through the example of a parser as an epistemic artefact, they show how mathematical model´s constructedness as things, is important for their epistemic constraints and affordances. They further argue that it is models´ materiality and their ability to represent that makes it possible to learn from building and manipulating them. This view connects models and simulations´ materiality as "knowledge artefacts" with their epistemological yields in mathematical manipulations. To this they stress that model´s material affordances regard the very conception of "representation", which they do not conceive in the classic philosophical conception of "mirroring" or correspondence, but instead as: ''a kind of rendering—a partial representation that either abstracts from, or translates into another form, the real nature of the system or a theory, or one that is capable of embodying only a portion of a system'' (Morrison and Morgan, 1999, p. 27). The general trend in STS' contributions to the simulation modelling literature is a pragmatic focus on how and what kind of effects that models and simulations produce in their surroundings. The great strength of these empirical practice-oriented STS-approaches is that they make a suggestive attempt to describe how such exotic practices as simulation modelling actually operates. STS scholars have for example described specific practices of mathematical manipulations at the CERN particle generator (Merz & Knorr-Cetina, 1997) and described how mathematical models help to organise work between experimentalists and modellers in meteorology (Sundberg, 2009).

To sum up what comprehension we have been able to gather from the existing literature on mathematical models and simulations thus far, we know that models and simulations' are things which material constraints and affordances enable human activity to mediate between theory and data (Morrison and Morgan, 1999). This mediation thereby also concerns models and simulations' material presence in the inter-subjective field of human activity (Boumans, 1999), where we can include the large-scale scientific enterprises where modellers collaborate with experimental researchers (Merz, 1999; Sundberg 2006, and Johnson, 2006). These STS accounts thus show how models and simulations in various local environments have gained pivotal roles due to their affordances in terms of extending both theory and experimental data. However, from the "universal" perspective of how models relate to their target systems the contemporary idea within philosophy of science, is that models and simulations do not correspond directly with their material target systems. Hence the theory-experiment split still sustains it´s dichotomical projection upon the dominant comprehension of what models and simulations are and do. Where one argument claims that computer models and simulations are experiments on theory (Galison, 1996; Dowling, 1999; Keller, 2003; Morgan, 2003), it is short-circuited by the other claim that models and simulations involve mathematical objects and therefore are strictly different from experiments that involve material objects (Winsberg, 2009; Petersen, 2012). The status of the discussion on models' epistemological status can thereby be coined as a question about their metaphysical status as being somewhere in between the material world and non-material theory. While there might be good reasons for seeing simulation models as occupying an uneasy space between theory and experiment (Sismondo, 1999), the preconception that experiment and theory occupies separate metaphysical domains, is however in direct violation with the nonmodern approach (Latour, 1991/1993) and the principle of generalised symmetry (Callon, 1991; Latour, 1992). In a nonmodern- and generalised symmetrical view, there can be no separate metaphysical domains. The material world and theory are instead merely two extremes that are connected by scientific reference through long cascades of re-presentations (Latour, 1999). From an ANT perspective, the epistemological question about what kind of knowledge mathematical models produce is instead an empirical question about how they can be understood to connect to their target systems. In other words, if we are to answer the epistemological question of how a model speaks of the world, we therefore need to understand how the model connects to the world. For this purpose the hybrid qualities of re-presentations enable us to examine both their different material states, and how these states provide means for inscriptions to travel between simulation model and target system. The micro-process oriented sociological quest for understanding the full range of material states of models that connect them to their various environments, can in this perspective also be seen as an approach that explores how these states produce epistemological effects.

Converting the Question of Truthfulness into one of Usefulness

Another major axis of discussion I have identified in the literature on simulation models concerns the distinction between models' usefulness and their truthfulness. Mathematical models always require some form of interpretation and connection to the rest of the world if it their impacts are to reach beyond themselves. However the truth-value of such connections is not possible to examine in the same way as truth claims are in purely closed mathematical realms (Hennig, 2010). Nevertheless, discussions about mathematics and mathematical modelling, especially within philosophy of science, have exhaustively circled around the fundamental question about how mathematics applies to the "real world", and the truth-value of mathematical representations of real world phenomena (Mancosu, 2011). An important implication of this is therefore to question how a model is made to satisfy the aims of a particular situation, instead of searching for absolute truth in how a mathematical model corresponds to the surrounding world (Hennig, 2010). Sismondo (1999) promoted this pragmatic perspective when expressing that models and simulations are more about usefulness than truthfulness. However the ways a mathematical model satisfies the particular aims of its' usages, are often linked to a belief in the model´s ability to speak of the phenomena it represents, with some degree of truthfulness. The use of models in science is generally linked to models' explanatory powers. Scientific use of models can therefore generally be seen to rely on the adequacy with which they represent what they are made to explain (Bokulich, 2011). Within science the usefulness of a model is therefore typically not separable form it's *perceived* degree of truthfulness. To articulate the distinction between model´s usefulness and their truthfulness, I connect this distinction to Rheinberger´s (1992, 1997) distinction between epistemic things and technological objects. Rheinberger's contribution was to provide an understanding of experimental science by distinguishing between the smallest functional units in experimental systems, by terming the stable context of investigation "technological objects", and the instable content of investigation "epistemic things". Knorr-Cetina (1997) re-interpreted this distinction by introducing computer's hardware and software to the discussion on how we understand scientific practice. Knorr-Cetina's argument was that Rheinberger's articulation of *technological* things is problematic "in the light of today's technologies, which are simultaneously thing-to-be-used and thing-in-a-process-of-transformation" (p.10). Knorr-Cetina (1997, 2001) instead proposed to displace the dividing line by including such technologies in the concept she rephrased to "epistemic *objects*", while she instead term the remaining category "technical *things*". Merz (1999) and Sundberg (2009) brought this distinction into the STS discussion on simulation models. Sundberg (2009) argues that meteorological models work as epistemic objects (Knorr-Cetina, 2001) through their use as representational models in scientific meteorology and transforms into technical things when used as operational models in weather forecasting.

The point that I whish to extract from the distinction between epistemic and technical entities, is that the usefulness of representational models in science, can be different from their usefulness in operational settings. In science the use of models are typically epistemological in the sense that their use is to enable scientists to better understand what they study. For a scientific purpose where a representational mathematical model is related to how that science speaks about the world, their model's *perceived* representational reality, and therefore its accuracy, can be seen as inseparable from its usefulness. In weather forecasting on the other hand, the representational models are used for operational prediction. This means that the models rely on technical credentials such as their operational reliability and ability to produce predictions that are in adequate agreement with observations (Sundberg, 2009). The practical implications of this distinction between scientists´ epistemic use of a model, and how the science feeds models or model outputs into technical uses of operational settings, are important when examining the full range of models and re-presentations that turn models into effects in their surroundings. In this perspective it is therefore important to understand how the various ways modelling, models, and model outputs can be understood as useful in their various settings.

An approach to illustrate mathematical models' usefulness is to assess how they contribute to produce alternative socio-material realities. The scope of this thesis is as mentioned to explore how simulation models and the practice of mathematical modelling play a part in realising new technology into society. Where the majority of previous simulation model studies have focused on applications in scientific contexts, this thesis sets out to unravel how mathematical modelling helps to apply scientific knowledge onto practical problems in society. In this light my study could broadly be phrased as a case of innovation rather than science. The focus on simulation models´ roles in technology development thereby attempts to expand our understanding of what kind of purposes that mathematical modelling can be used for. This focus thus intends to contribute with a new understanding of how modelling outputs are translated into effects through technology.

Chapter Four

Entering Uncharted Territory

From research idea to empirical access and data collection

One afternoon during the fall 2009 at the technical university where I had just spent the last 7 months to write my masters dissertation I was on one of my many daily trips to get coffee. Unlike the typical sleepwalking that had been part of the intense work my project-partner and I had put in to finishing our masters dissertation, this afternoon took an unforeseen turn. One of my former lecturers suddenly entered the lunchroom from the hallway and asked whether I had seen his email. While I had absolutely no idea what he referred to, his question developed into a fruitful conversation about mathematical models –a subject I had not before been presented to as a research topic. The idea, that the lecturer who later became my PhD supervisor Professor Torben Elgaard Jensen, presented me to, was about performing an empirical study on how mathematical models were utilised in product developing organisations. During the following six months, this coffee-break idea materialised into a project proposal of which I was granted a three year independently financed PhD scholarship to do this thesis.

However, one thing is to have a good idea, another thing is to make it a doable research project. The purpose of this section is to present how the idea behind this thesis became an explorative ethnographical data collection. A study, that led me to uncharted outskirts of contemporary scientific and technological development in an industrial environment of our society. The research project's empirical aim had, from the outset, been to conduct a participant observation study (Spradley, 1980) of actual lived practices that in one way or another incorporated work with simulation models. The intention was thereby to produce thick descriptions (Geertz, 1973; Yin, 2003; Flyvbjerg, 2006) to allow further theorising and discussion by putting additional flesh on the bones of our conception of simulation models and the practice of modelling. However such descriptions relied on an access to modelling activities that were not easy to obtain. During 2010 my search for potential cases studies led me to perform more than 12 semi-structured interviews with scientific advisors, product development managers and modelling experts from a range of large Danish and international companies. This line of interview brought me information about modelling activities at Novo Nordisk, MAN Diesel, Oticon and Rambøl. -Activities that ranged from virtual clinical trials, diesel combustion simulation, CAD/CAM and FEM of hearing aids, and simulation of urban drain water. I also interviewed a number of academic researchers from various fields at my university. Their work ranged from shipping line modelling, duty roster optimisation, and simulation of blood circulation in relation to humans' degradation of medical compounds. For various reasons none of my informants could unfortunately offer me anything but formal interviews about their work. They could thereby not grant me the access I was seeking to study modelling first hand as a fully fletched practice that unfolds as part of a greater organisational ecology. However, by rolling the snowball (Bijker, 1995) an informant who had just finished her PhD research on mathematical modelling pointed me to her former supervisor. He had knowledge of a number of interesting on-going and future projects that entailed mathematical modelling in cooperation with private companies. It was through one of these potential cases that I late in 2010 became acquainted with the regulation project. Although I didn't know it back then, the regulation project would come to form the complete empirical basis for my study. Whereas the empirical work I had conducted up until my participation the regulation project, is not directly used in this thesis, it was however central for developing and reshaping my research interest in, and general understanding of, mathematical modelling.

The regulation project started January 2011 and was to run for two years. The purpose of the regulation project was to develop new adaptive regulation solutions for industrial process equipment. The regulation project was formed around three private companies and two academic research groups from two different universities. The private companies were the project holding consultancy company CORE A/S who specialises in development and implementation of industrial process optimisation and control. The other big private participant was the production company, Daka bio-industries who were the particular end consumer case for the project's process control solutions. The last private participant was the process equipment supplier Alfa Laval. From the universities there was a research group from the Mads Clausen Institute (MCI) at the University of Southern Denmark (SDU) that specialises in representative physical modelling of industrial processes. The other research group was the Centre for Embedded Software Systems (CISS) from Aalborg University (AAU); this group had experience with developing industrial process regulation.

My participation in the regulation project was thereby a unique chance to become part of a newly started project where I could study first hand how the collaboration developed between mathematical modellers, technical consultants, and a large production company. Previous "thick" descriptive contributions to the simulation modelling literature (Merz, 1999; Sundberg, 2006) are to my knowledge primarily based on interviews and secondary sources such as technical literature and written email conversations (Merz & Knorr-Cetina, 1997). Conducting a study based on participation and direct observations of how the regulation project's messy practices unfolded in their natural environments, therefore held the potential to form a unique ethnographical contribution to the literature on simulation models. It was this kind of empirical engagement that had proven so rewarding to the origin of the laboratory studies (Latour & Woolgar, 1979/86). However, while the regulation project was promising by featuring a diversity of participants, activities, different organisational settings and use contexts, I still relied on getting first hand access, in order to realise its full empirical potential. During the first half of 2011 I was invited and participated in three coordinating half- to full day meetings. The February meeting took place at the factory near Løsning. In order to introduce the project participants to the production environment, this meeting included an introductory walkthrough of the factory's production. This walkthrough forms the basis for the description of the factory in chapter Five. While these meetings presented me with information about the different project participants' work, it became evident to me that I had to make myself useful to them, if I were to closer to their practices. I had to realise my "legitimised" access into a more direct involvement. Because the project coordinator expressed an increasing interest in getting the project participants to promote the regulation project by externally communicating "the good story", I offered to devote my assistance to that task. This was an attempt to justify my participation by redefining my role into a contributing member to the project. My intent was to give the other project participants a practical reason for inviting me to their activities, that the "legitimisation" offered by the non-disclosure agreement failed to provide on its own. My new commitment with the project meant that the project coordinator asked me to join him in his field expeditions to the various sites of the regulation project. During the last 6 months of 2011 I followed the project coordinator's everyday work as he travelled around and coordinated activities at the different sites. Through these expeditions I came to visit the various industrial facilities that were part of the regulation project collaboration. The project coordinator's work primarily centred on meetings with the production managers at the various sites. During these meetings they talked about what operational challenges they were facing, and planned and followed up on regulation testing. Sometimes they also walked through the production sites. Besides a good handful of coordination meetings and technical meetings at Aalborg University, University of Southern Denmark in Odense and in Sønderborg, the coordinator brought me on about 20 all-day field expeditions to the blood plasma spray-drying factory at Lunderskov, the wastewater treatment plants at Aalborg and at Hedensted, where I observed the full extend of regulation model implementation and testing (Chapter Seven). The majority of these field trips went to the wet process production at the factory near Løsning. The Løsning factory thereby became one of my main empirical sites because I was able to develop unique insight concerning how it operationally transformed during the regulation project (Chapter Eight). While one of the experienced operators gave an additional walk-through around the factory, he told me that they had often experienced problems with the new regulators. He believed that it would be highly valuable for the regulation implementers to stay at the factory for a week and experience the extended operation of the regulators. As he said, this would enable them to see for themselves when and how the regulators caused problems. I thereby became convinced that the Løsning factory held a great empirical potential for exploring how and what kind of effects the regulation models produced in the production environments, where they were implemented and tested. I decided to setup a 24 hours day and night study of operational routines at the factory, in order to understand the wider implications of the regulation models. However first I had to negotiate that kind of access to the production. By committing myself to conducting manual tests of a new regulation idea on the drier machines, I achieved the practical reason I needed for gaining the extended access to the factory. At the factory I was given a desk station inside the control room, from where I could directly observe the activities of the operators and the automation consultants, who also worked from the control room. When nothing interesting seemed to be happening around me, I conducted my manual testing of the regulator. Most of the time however, I spent on joining the operators during their walkthrough routines where they inspected their production lines. In this sense I very literally "follow[ed] the actors" (Latour, 1996) – which in this case meant to follow every step of the human operators around the factory, during their 8 hours shifts, paying close attention to what they did, and what things they engaged with. I also observed how the organisation of work took place inside the control room; how the three daily operator shifts took place approximately 20min before to 5min after 7am, 5pm, and 12pm, respectively; and how trucks and craftsmen that visited the production were coordinated the factory's operation. I also joined the operators and the automation consultants when they ordered food and dined in the small lunchroom adjacent to the control room. Because the industrial environment at the Løsning factory, and the other industrial locations, were very noisy, audio recording proved too impractical. However the nature of my empirical engagement, the constant stream of people in and out of the control room, and my casual, and often personal, conversations with the operators and the automation consultants, also meant that I had to rule out audio recording – both for practical and for ethical reasons. Instead I based my documentation on producing a great body of handwritten field notes and an extensive amount of photographic snapshots of the events I participated in. My empirical commitment to the operational transformation of the Løsning factory resulted in two descriptions. One describes the transformation into an automated operation (Chapter Five). The other description draws together the regulation project in terms of a discussion of the displacement effects it produced at the factory (Chapter Eight).

Another strand in my empirical work was to study the modellers' practices. During the summer coordination meeting 2011, I expressed to the modellers, that I wished to study their modelling activities and participate in their meetings and other relevant work to their modelling. At that time, the representative modellers at MCI had already defined and started to computerise their first representative model. This was a model of the thermo screw machine, that we all had been introduced to 6 months earlier during the walkthrough at the Løsning factory. However, luckily for me, the modellers at MCI were to model additional production machines during the fall 2011. I thereby managed to participate in the very first modelling meetings that later resulted in the representative drier machine model. These meetings were initially held at the modellers' own offices and later developed to take place in their larger teaching- and conference rooms. Due to the more planned and anticipated nature of these meetings I had the chance to arrange for them to be audio recorded. I could also supplement these meetings with semi-structured audio-recorded interviews with the modellers. I also negotiated an extended study of the modellers' everyday work where I got access to study the work of two modellers first hand for a week during January 2012. My approach to documenting the everyday work of the modellers, was to perform audio-recorded contextual interviews (Horgen et. al, 1999). Because the modellers' practices were mostly characterised by computer activities, I could sit next to them and interview them, while they worked, by asking into what and why they did what they did. I also participated in the modellers' teaching activities and a bulk of small ad-hoc meetings they held to discuss ad-hoc problems with the current states of their models. This empirical strand of my work resulted in the analysis of the representative modelling in chapter Six. My empirical engagement with the modellers lasted until December 2012 and resulted in a formal invitation to present my work at one of their institute's weekly seminars. During the summer and the fall 2012 I also corresponded with the modellers about their empirical engagement at the factory. They sought to extract data they could use for their model validation.

Although my original plan also entailed to study the modelling at CISS, I realised that their work were postponed and thus came to have little effect to the Løsning factory. In order to develop their regulation models for the process machines, CISS had to receive finalised versions of the representative models that were developed at MCI. Because MCI's work on their representative models went on and stretched far into 2012, the related modelling at CISS did not materialise in time for me to study it. Instead they worked on developing specialised models for decanter machines in cooperation with Alfa Laval who manufactured the decanters. Because this work lived its own detached life from the rest of the regulation project, I chose to concentrate my study on the representative modelling at MCI, the project coordinator's development and implementation of regulators at the Løsning factory, and the resulting displacement effects I could observe in the operation of the factory.

Throughout the almost two years of my participation in the regulation project, I have been on what amounts to 50 all-day visits to the 9 different locations where various parts of the regulation project took place. I produced around 400 A5 pages of handwritten notes and sketches, took more than 2000 photographic snapshots, recorded about 30 hours of contextual interviews with modellers and 15 hours of modelling- and other technical meetings. During my project participation I was also grated access to the project's file sharing. This supplied me with well over 300 written A4 pages of material that was uploaded by the project participants. This material concerned meeting summaries, the formal project description, the fund application, elaborative planning details, a range of academic papers on regulation and related technical literature. Due to both the amount and the different nature of my material, I chose to guide my transcription and coding after an analytical selective principle where I first traced the major themes in my material. I identified these tendencies by following the material scripts. One major tendency was the way raw product at the factory became raw data, which then were condensed and put together with inputs from qualitative interviews of the operators to form the process description report. This report and a number of excel documents containing raw data then finally ended at the modellers' disposal. Parts of this process are described in Chapter Five. Another major tendency was how these material scripts were manipulated together with other scripts, derived from physical theories, and materialised into mathematical scripts, that could then be computerised (Chapter Six). And finally, a third tendency was how these mathematized and computerised scripts were re-embedded to the factory's operational settings, and translated into a great variety of other scripts, such as behavioural aspects of machines and human operators (Chapter Seven and Eight). By closely tracing the tendencies of how these scripts moved and transformed throughout the project, I selected, zoomed in, and focussed my detailed retrieval of information to concern the events I deemed most important to explain the construction, use and performative effects of mathematical models.

Chapter Five

From Pig Carcases to a Body of Information

Following Regulation Modellers into the Field

In order to investigate how mathematical models are applied and become useful, they need to be understood as a part of the specific historical, local, and socio-material context in which they serve certain purposes and generate certain effects. A distinct feature of the mathematical modelling that is studied in this thesis, is that it concerns regulation of industrial process machinery. While previous studies in the literature on mathematical models have centred on scientific applications, this study's differs by looking at how modelling can be seen to generate effects in the rest of society – in this case, a wet process factory.

This empirical chapter will introduce the factory near Løsning as both the context for, and the content of, the modelling in the regulation project. The idea is turn back time to a cold February morning in 2011, and walk along the other regulation project participants, during their introductory walk through the factory. We will thereby both get introduced to the regulation project participants –and to how they were introduced to the messy and complex environment that made up the target system for their later representative modelling. The representative modelling will be the subject of the following chapter six. The present chapter thereby also serves to illustrate the kind of environment in which the regulation project later was to implementation their regulation models. A process we will pay close attention to in chapter seven. Besides clarifying what kind of environment the regulation project was dealing with, a third purpose of this chapter is to illustrate the situation at the factory prior to the regulation project. This before picture thereby serves as a reference for the after picture that will be discussed in chapter eight.

The representative modelling of the factory that we later investigate in detail, was be done by a group of theoretical physicists in a scientific research environment. In this sense, we can see this chapter to introduce a particular locality of society that the physicists were to connect with scientific knowledge through their models. As previously mentioned, the literature on simulation modelling already contains numerous examples of how representative mathematical modelling connects theory with data within a various scientific contexts (see for example, Winsberg, 1999 or Sundberg, 2008). What is then different about connecting this factory near Løsning to theory, than to connect scientific experimental arrangements to theory? A way to illustrate this difference is to think of the factory as a kind of *wet laboratory*, which data output was to be analysed by means of simulation modelling – at the *dry lab* (Johnson, 2006; Merz, 2006). In this line of thinking, the walk through the factory can be read as the characterisation of a production that is not only setup to turn raw product into output product, but also to produce data for modelling. Another way to frame the difference between a scientific context and that of the regulation project, is thereby to ask how well this particular industrial production works, when interpreted as a scientific laboratory? Because this chapter describes the factory at a state before the regulation project started to influence its operation, it can also be read as a reflection on how much the factory would need to be transformed in order to be made compatible with the standardised forms that re-present scientific knowledge about the world. How exactly this connection is made to physical theory, will be treated in the next chapter (Chapter Six).

If we were to see mathematical modelling the way many philosophers of science have presented the subject (see for instance Winsberg, 1999), the craft of modelling would appear to be almost exclusively about thinking –as a practice that articulates theory by means of the mind. By contrast to analytical philosophy, Latour's (1999) empirical philosophy demonstrated by circulating reference, presents scientific practice as meticulous manipulation of hybrid matter-sign things – hence also the material world. By following the empirical lead demonstrated by Latour, we can see the modellers' engagement with the factory as an early attempt to tame the wilderness of the factory – an attempt to cultivate and control extraction and abstraction of data and information for their later modelling activities. Thus, in the case of the regulation project, we do not start from theory with first principles, but with a walk through the factory. What I want to explore through this field study, is thereby how the modellers related to the production at the factory through construction of reference. A construction of reference that was intended to ensure that their later models would become useful re-presentations when brought back to the production in the shape of regulators. What I more specifically seek to answer is how the regulation project, extracted information while maintaining reference to the factory. What kind of reference can we understand that the regulation project produced, in order to ensure that the information they extracted for their modelling, would enable their models to return and generate intended effects at the factory? These questions will not be sought answered by this chapter alone. Instead they serve as an underlying reflection that drives this thesis' quest to understand the regulation project and what kind of context it performed around its modelling activities. What kind of epistemic enterprise can we can recognise the regulation project and its modelling activities to have produced? –If not a purely scientific one, then what kind of epistemology can we make of the regulation project?

To provide an adequate basis for understanding what the regulation project, and its modelling, set out to do, his chapter will start by introducing the basics of the factory's production and the aims of the regulation project. The structure of this chapter is thereby to introduce the basics behind the regulation project and the factory, for thereafter to walk through the production together with the project participants. Lastly, the chapter will place the factory into a historical context of an on-going automation project, to present a more aggregated picture of the factory and what was tried to be achieved though the regulation project.

Energy-Efficient Regulation of Separation Processes

This chapter is based on a field expedition to an industrial production facility near the little town Løsning in the outskirts of Denmark. The factory was part of the Danish production company "Daka Bio-industries" who processes pig carcasses and other animal waste products from slaughter plants. At Daka they refer to it as "product". The reason for the field expedition was to take part of the regulation project's start up. The purpose of the regulation project was to analyse and optimise the production at Daka by developing and implementing new adaptive regulators. While Daka with its numerous industrial installations around Denmark, made up a significant commercial potential on its own, the ambition of the regulation project was to develop model-based regulation products with wider applicability in the process industry. We can thus see Daka's role in the regulation project, as well as that of the factory we were visiting this February morning, to serve as the case, for which the regulation project could technically develop and market mature regulation solutions. CORE, the project holding consultancy had set up the project and organised coordination between the project participants. CORE's special technical expertise was to conduct process analyses on the factory's production. They also held a patent on an adaptive regulation model that was to form the basis of the regulator solutions that the project developed. While CORE didn't want to reveal too much technical details about how their adaptive regulators worked, its basic operational principle was to adapt its machine steering based on tendencies in the machines' performance history. The advantage was according to CORE, that the adaptive regulators were better at prevented machine oscillations – a problem that often is associated with "Proportional-Integral-Derivative" or "PID" regulators because their short operation cycles "over steer" slowly reacting machine process. In basic terms while typical PID regulators tend to over compensate, the adaptive regulators should instead read the extended process tendencies and thereby compensate it's steering accordingly. Besides the representatives from Daka and CORE, we also had company of representative from Alfa Laval who manufactured industrial process equipment, as well as representatives from the two universities, and then finally me – the odd observer whose role in the project had not yet been defined.

In order to get a better idea of what kind of problems that the regulation project were facing at this factory, we need to further elaborate on what kind of production processes that were conducted at the factory. If we follow "the product" through the factory, it arrives at the factory as leftovers from slaughter plants. Primarily the factory received pig carcasses, but occasionally other animal waste was received too. This raw product is transported by trucks and received in large containers dedicated to soft, hard or mixed product. This distinction is quite important because the condition –the mixture of hard and soft product, has a great effect throughout the production processes. From the receiving containers, the product is then transported, mixed, minced, grinded, heated, pressed and scraped in order to separate its content into different substances i.e. liquidised fat, protein, and wastewater. Dedicated processes then further refine these substances, in order to make fat for biofuel production, protein powder for food production, and cleaned wastewater that can be released to nature.

Figure 5.1: The Løsning factory seen from the parking lot. Picture taken by the author 2011.

Before the expedition I was warned about the special odour that the factory's processes was known to produce. I was even advised to bring spare clothes for the trip home. When we arrived at the parkin lot and opened the car doors, it was thereby no surprise that our nostrils were met by an intense and very noticeable impression. One thing was certain –the factory had certain characteristics that we had to get used to. Even when we got inside the meeting room, the smell of heat-processed pork and vast quantities of raw pig carcasses was still unmistakable. The meeting started with an introduction of the project participants. Because it was the first meeting where all parties participated, many participants had not met before. After this, the director of Daka went through what they did at the factory and what kind of production challenges he believed they were facing. I will shortly introduce a few of these challenges to provide some insight to what we are dealing with.

In order to produce protein meal and raw fat for industrial purposes, Daka's main challenge was to remove the approximately 60 % water content in the raw product they received from the slaughter plants. Another primary task was to remove contagious risks in the raw product and divide it into the protein- and fat products that they could sell to other industries –for instance animal fodder and biodiesel production. What appeared to be among the general concerns was the energy consuming, and therefore expensive, separation of water. Another concern was that the raw fat represented vastly superior market value than the protein content. A practical challenge related to this concern was that it was some fat content inevitably ended up with the protein meal and thus represented less value because its market price was around one fifth compared to that of raw fat. Furthermore it was difficult to control the exact amount of protein content in the protein meal. Daka produced two qualities of protein powder, one that guaranteed a minimum of 40% protein content and another with at least 58% protein – the latter was of course more valuable. Daka tried to adjust these levels by mixing substance with high protein content with substance of lower protein content in order to approach the goal levels. At that time we were told that Daka's protein meal that was specified to be 58 % contained around 61-62 % protein, which meant less profit. One of the great challenges that Daka faced, was variations in the quality of the raw product they received from the slaughter plants. The raw product quality varied by containing various degrees of hard components i.e. bones, and various levels of soft tissue i.e. entrails. The specific composition of soft and hard components had great impact on the various processes in the production line. Daka tried to manage these raw product variations by having a differentiated raw product reception that divided the received raw product into hard, soft, and mixed composition. While this separation made it possible to mix the three raw product qualities for a more equalised composition, the following production processes still faced quite large variations. One reason was that the factory had no exact measure of the raw product compositions. Another reason was that the more challenging soft product deteriorated faster than the other compositions –meaning that the operators chose to process it as fast as possible. Another dimension to this raw product challenge was that Daka was based on a limited liability constellation having 19 (16[1]) different Danish and Swedish owners from the meat industry. Daka's raw product suppliers were thereby also their owners. This meant that

[1] 16 owners due to http://www.daka.dk/page356.asp 14/2-2011

Daka's options to control what raw product they received was limited due to the conflicting interests between those of their owners –who wanted to dispatch their waste for the greatest possible profits –and those of Daka who wanted to control their production's process conditions and extract the greatest possible value for the least amount of expenses. This complication thus meant that Daka had to provide savings –not alone in their own production, but rather as a specific part of the entire meat industry chain that both owned Daka and supplied Daka with their waste products. To further complicate this already rather complicated ensemble of different economical interests and raw product –related production challenges, I was later told that the marked for animal waste products had greatly intensified because Northern German and Chinese purchasers pushed the prices up. For Daka, this translated into worse raw product quality and even smaller profit margins. It was therefore even more important for Daka to understand how their production depended on different variables –both because they now more than ever needed to increase process efficiency, but also because they needed to become more knowledgeable about the correlation between the raw product quality, the running costs, and the expected putout value of the final products. In other words, how much could they afford to pay for the raw product?

At the end of the presentation, CORE's director, who was in charge of conducting the process analyses of the production, asked into how much energy each process consumed and the quantities of the wastewater and sludge that the factory produced. He also asked into how the containers were divided. Who that was responsible for the data projections of the production? CORE's director also emphasized the importance of finding out what the specific process parameters were. These parameters could both be understood as what data that potentially could be extracted from the various processes, and as what kind of success parameters they should aim to optimise for each sub-process. The CORE director further asked into what Daka considered their biggest challenges. Based on this line of questions we can thus see CORE's director to express two kinds of interests; one was of an analytical kind and concerned the delimitation of the major production problems –hereunder the identification of success criteria for the various sub-processes. The other interest he expressed was rather about the availability of production data. Data that could both serve as means for process analyses, but later on also as means for creating operational connection between the adaptive regulators and the machine processes they were to steer.

Approaching the Stench

After the introductory meeting we went on a factory tour to see and experience the production processes on the site. In order to minimise the risk of polluting the sensitive processes, which by the way, follows the same regulations as food production –we were to walk backwards through the process-line. We therefore started at the cleanest and most controlled part of the production an then moved on to the dirtier, less controlled parts for finally ending where the raw product came straight from the suppliers. This was standard operational procedure to prevent that contaminants from the raw product were transferred to the output products. Before we entered the production we were each handed a white suit to wear. First of all this was to avoid contaminating the production. Secondly, it was to minimise contaminating us, and the clothes we wear. Cocooned in white suits we entered the slightly raining outdoors, and walked towards the vast grey concrete buildings housing the process section of the plant. The first part of the plant we visited was where the protein powder was divided into 40% and 58% and packed into large plastic bags they called "big bags". When entering the large grey concrete building, we were to put on clean shoe hoses before entering the 'clean' area where the meal processing was conducted. The main machinery consisted of a row of large sieve installations, which were supplied with protein meal from above, by an extensive pipe system in the ceiling. Though the facility was not operating during our tour, the prior operation of the machines surely left its traces. There was a dusty feeling in the air carrying a smell of the protein powder and leaving visible traces on every surface. 'Clean' surely meant 'sterile' according to health and safety regulations within the food production industry. But in relation to a household, clean certainly have a different meaning. At this facility we talked about how the process worked and how it was managed and controlled. The basic principle was that due to the grinding, the high protein content powder had a grain diameter below ca. 2,5mm. The lower protein content powder however had a larger grain size. When the mix of powder was sieved, the small high content grains went through the small holes in the sieve, while the larger low content grains didn't. These instead had to be poured over sides of the sieve where it could be collected separately. Below we can see how this process was visually re-presented on the monitors inside the control room that we were to visit after the sieves and meal packing. The stippled red oval shaped line is added to point out the sieves we encountered.

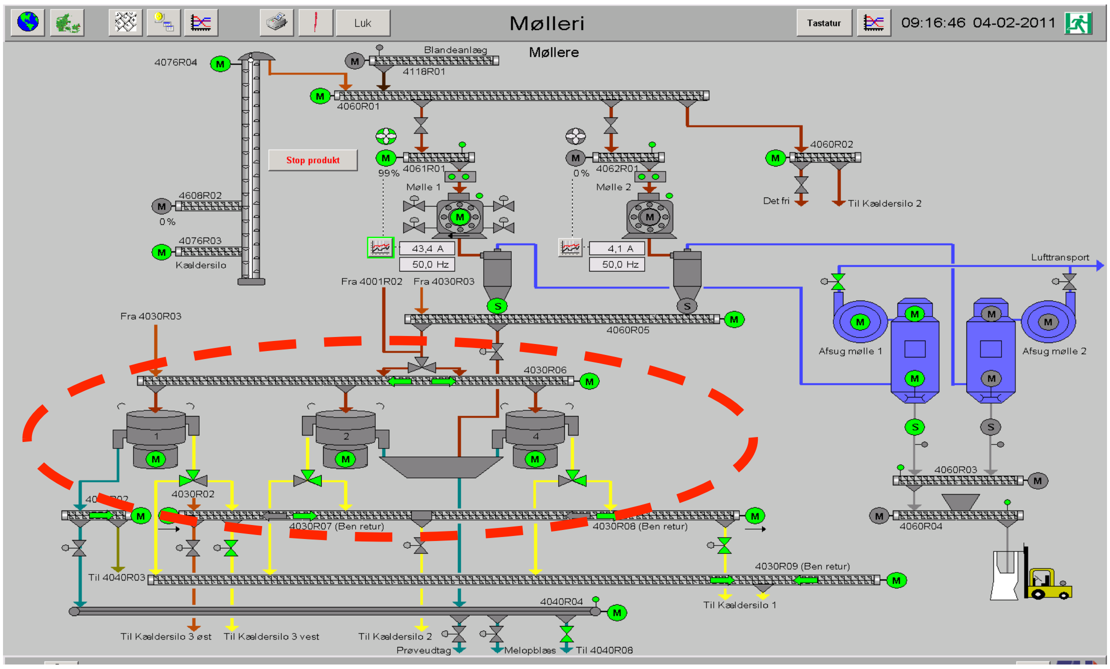


Figure 5.2: Screen projection of the factory's milling facility. The red stippled line indicates the three sieves. Illustration from the power point presented at the meeting 4/2-2011. Red stippled line added by the author.

A central problem was the aforementioned adjustment of the protein level. At this state, it was the operators who had to manually to mix the high level and low level meal to achieve the right concentrations. As their current 58% standard was around 61-62%, it translated into monetary losses. CORE's director asked into the sensory system and available data from the production. It appeared that new sensors had been installed but were still not accurate enough to use. The installation of sensors was especially problematical because of technical difficulties relating to measuring the flow of meal. This industrial machinery, connected through feeds and outputs seemed at once both very present due to their noticeable physical traces i.e. dust and smell, but also very distant at the same time. The very metal bodies that generated the production processes also separated them from their surroundings. While we were standing right next to the machines, we had very little information about what went on inside their hulls. Making trustworthy data re-presentations of the meal flow seemed to be a technical challenge that was still too complicated for the factory to handle. Direct human control appeared still to be the most reliable solution. In terms of the regulation project's ability to produce operational references to the production, automated sensory data was however a necessity. Measurement devices were placed all around the facility in order to 'look into' the otherwise black-boxed processes by supplying us with data concerning temperature, pressure, humidity or other parameters. The same material conditions supporting the process were also obstacles that separated us from the processes, and at the same time the terms for being connected to the process. These material settings –being the flow of processed pork bones, lumps of flesh, skin and entrails, as well as the stable material structures composed by the conveyor screws, pipes, grinds, boilers and storage tanks, constituted tough and complicated working conditions for sensors. A sensor that detects the surface temperature on a piece of pork could not necessary be considered representative for the core-temperature of that piece. Neither did it produce a trustworthy average temperature of the flow, because the pieces varied both in size and in content. These uncertainties regarding the composition of the product that went through the process-line, thereby also translated into uncertainties regarding the representative reality of the measurements. The detectable surface temperature was just one example of this. When the professional and experienced modellers asked into the availability of data they sought reference. Reference relating the modellers to what was going on at the facility. Reference, that by the modellers could be mobilised, interpreted, and combined with physical knowledge though mathematical know how in order to create models that related reference parameters with regulator steering variables. The data might not have been flawless, neither perfectly representational of the processes under exploration, but they were however the practical operational reality that the modellers had to work with.

After the dusty visit of the sieves, mills and meal packing, we went out in the rain again to head deeper into the cluster of buildings at the plant. A distinct experience walking around the facility was how the smell changed from place to place. A constant underlying scent of cooked pork was always present, but other flavours occurred and left again, as we moved through the factory thus providing us with distinct traces of the nearby processes. Though they were in no way interpretable by us. These odours and their subtle nuances were probably quite recognisable for the operators and other workers at the factory who's possessed tacit know how on running the facility, by using whatever sign or clue they could make sense of, in order to adjust and service the machinery. Our guide on the tour told me that the operators, who controlled the machines, often had no formal training. He furthermore told me that each operator was in charge of a small domain of the process-line that consisted only of a few machines. The operators therefore made sure to keep their own domain going, and according to out guide, had often only little comprehension of the larger chain of machines. Furthermore, to keep their machines going, the operators related to what made sense to them. For instance whether their machines in the 'felt right' or generated unavoidable problems like spilling substance on the floor, or worse, stalling the entire process line.

From the Perspective of the Control Room – a Centre of Data and Re-Presentations

"For the World to become knowable, it must to become a laboratory"
Latour (1999), Pandora´s Hope, p. 43

Figure 5.3: An empty control room. Picture taken by author during 2011

The next stop was the newest facility at the plant; the control room. As an example of a break with a decentralised scheme of operation, where proximity to each sub-process was the operational premise, the central control room replaced four smaller sub-domain operator rooms. In the control room all the data from the entire production was collected and combined on the monitor-screens, where the data was represented as numbers and graphics. Entering the control room from the rainy outside, this new and very clean building was almost like entering a different world. We were even to clean our shoes in order to avoid dragging in dirt from the outside. Where previously the reason for taking on shoe bags was to avoid contaminating the production, it was instead now to avoid dirt –keeping the control room 'house hold' clean and comfortable for the operators. We were told that the operators were very happy to get this new control room, and therefore put a lot of effort into keeping it clean. By stepping into the control room we had stepped into a reality of clean comfort that was supplied with production data, in order to distance us from the rough, dusty, and smelly reality of the physical machinery. The distinct underlying smell of processed pork, were still present though. As we can see in figure 5.4 below, this centre of data enabled the operators to get an overview of the entire process line, as opposed to only being able to monitor the separated sub domains when working in close proximity to the machines.

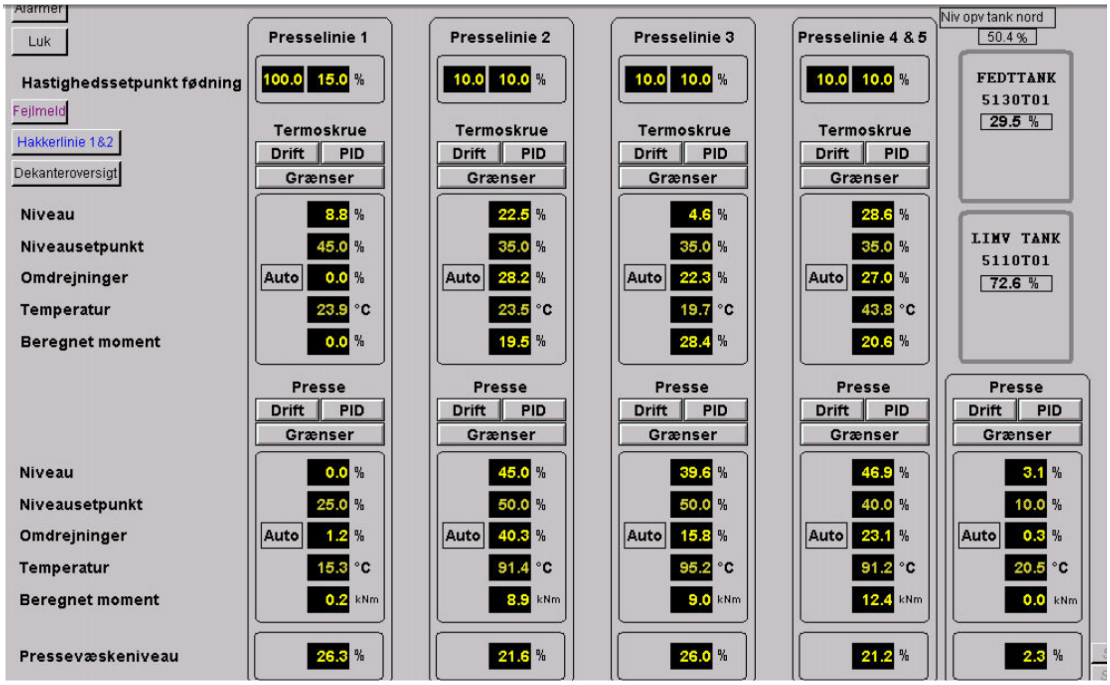


Figure 5.4: Screen dump from the power point presentation presented at the February meeting showing how the graphical interphase present the operators for on-line data projections of the machine processes. This screen shows the thermal screw and press line sub-domain

In figure 5.4 above, we can see how the data from the production was nicely ordered and laid out in vertical colons and horizontal lines. Gathering and presenting the production data in this way provided the operators with an overview of the process lines. In figure 5.4 we can see each individual process line as one of the vertical colons. Data that concerned the feed from the raw product reception is in the top vertical line at the screen. Below we see data re-presentations of the subsequent sub processes. The thermo-screw is re-presented by the subsequent five data parameters. Lastly we can see the six data parameters re-presenting the press machine at the bottom of the screen dump. Looking at the process line 4 & 5 (furthest to the right), it can be seen that the temperature is raised from the thermo screw at 43.8 degrees Celsius to 91.2 degrees at the press. The other process-lines also show how the product is heated through the thermo screw. Process line 1 deviates, because it at the time of the screen dump was not up to full speed –revealed by that the temperature is lower in the press than in the feed of the thermo-screw.

At a comfortable distance the control room thereby provided closely monitoring of each sub process through the data re-presentations. This could be done by the operators by manoeuvring around the flat screen based data interphase's various re-presentations of the production.

Figure 5.5 to the right shows the intake of raw product for process line 4 as shown to the operators on their flat screens. At the top left of figure 5.5 we can see a projection of the containers that receive raw product delivered by trucks. The green path signifies the path of the raw product from the containers, through their mixing and onto the mincers before the thermo screws. Because we went through the production backwards, the raw product intake, mixing and mincing were the last part of the process-line we got to visit. What we cannot not see from the screen dump but from the picture (figure 5.6) is the enormous facility housing the large containers, where the trucks dump the product from the slaughter plants. To enter the facility, trucks drive up a sloped piece of road elevating them from ground-plane a few meters up to the large roofed tarmac surface. Here they are directed to the right containers according to the nature of their load –being either soft, hard, combined or bristles. When delivered to the containers, the raw product is transported further into the facility by a large rotating conveyor screws in the bottom of the containers. When the trucks have delivered the

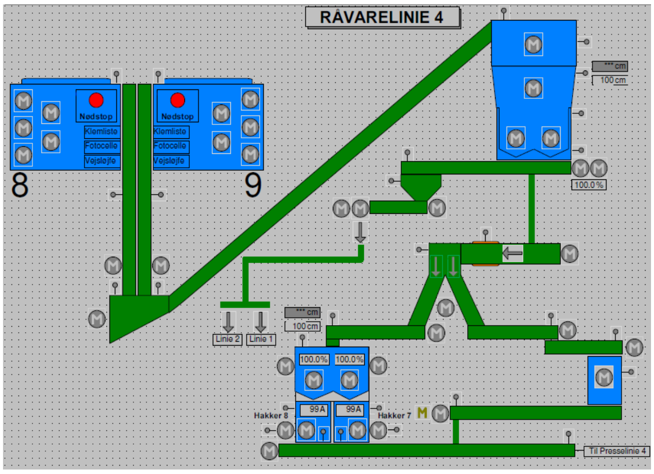


Figure 5.5: Re-presentation of the raw product reception. This picture is from the power point presentation at the February meeting 2011.

Figure 5.6: Own photo of the raw product reception. 2011.

Figure 5.7: Own photo of a raw product container. An operator is seen while trying to remove a misplaced plastic box that came with the raw product.

product, they turn around and park shortly in the cleaning area next to the exit, where the drivers clean them with the accessible water, before they leave the facility the same way they came. As mentioned during the meeting, one of the most difficult parameters to control for the factory was the composition of raw product. This challenge was partly approached by diverting the product in each truck to the right containers according to the reported condition of their load. Based on the raw product's visual appearance, the operators could mix the hard, soft, and combined content. This was done based on the individual operators' comprehension that neither too soft, nor too hard product was best suitable for the following mechanical separation processes.

Figure 5.8: Picture taken by author during 2011 of the factory fall housing the press-lines with the mincers, the thermo-screws and press machines.

At our tour we also encountered the facility housing the thermo-screw and the press, together with the mincer and the conveyor screw. This facility is placed below the tarmac covered plane where the trucks deliver product to the containers. Connected through a large conveyor screw to the containers with the raw product, we could follow the flow of the product from mixing to mincing, to the thermo-screw and to the press. All these machines were housed under a large shared roof. To say the least, this facility was large; a few stories tall with gangways following the elevated processes and transport-lines with many parallel process-lines, places aside each other. Filled with a characteristic and undeniable smell, this shared space stretched from where the raw product entered from the containers –and all the way to where the transportation system brought the product that left the press and the scrape basin on to the drier machines. One could easily get lost, and at this first visit any illusion of getting an overview of the entire process was completely annihilated by the ungraspable vastness of this mechanical jungle consisting of pipes, rotating conveyor screws, steaming heaters, press´s, scrapers, and decanters.

Figure 5.9: Picture of one of the many spills. Photo by the author, 2011.

An unavoidable impression of the production, its processes, and the contents flowing through its veins, were the sporadic pools of liquid content that at various places were spilled on the concrete floor. Not only one place, but quite a few places, this indefinable soup were caused by presses that "vomited" due to being incorrectly fed and adjusted. This was a phenomenon that the operators sought to avoid through careful adjustments of the production. For instance by getting the right mixture of raw product content. This impression was indeed a very visual and physical reference of the operational reality at the factory. – And the potential consequences of not hitting the right setup of the production. These peptide soups did not seem to be rare phenomenon. At least the staff and our guide did not seem too affected by these pools lying around on the floor. This left me with the impression that these soups were an everyday phenomenon at the production.

An important operational parameter was the temperature setting of the thermo-screws. These were set manually by the operators to make sure that the product was heated sufficiently to make the fat content to melt. When the heated product entered the press machine all liquid content would be mechanically separated as run off fluid. Because the solid content that left the press would go directly to the driers and thus eventually become protein meal, it was central to ensure that, as much fat as possible would run off as liquid. The general understanding among the operators was that the press machines torque was the key to make the best separation. Keeping the press torque at a high level, were by many operators seen as the most important separation process quality indicator. The major challenge related to generating high torque levels in the press, were when the raw product was too soft –i.e. having too much entrails and too little bone content. These challenges thereby referred back to the composition of raw product and the mixing of raw product. The operators also told that they inspected the solid output of the press, by squeezing it with the fingers to ensure that it had "the right feeling", which the operators used as an indication of high quality separation.

Based on the experience of walking through the factory, it should now be clear that the factory would fail as a scientific laboratory. The operational reality of the factory did however provide a great deal of data re-presentation of the production processes, through which future regulators could connect to the production. In the literature on scientific models, we are often presented with the idea that mathematical modelling is applicable and justified where data is sparse (Sismondo, 1999; Winsberg, 1999). However in the case of the regulation project, we instead face a factory that was quite rich on data. The problem with this data was rather its reliability. The vast amount of data also meant that the regulation project had to delimitate what data parameters through which they would try to control the production in order to obtain the best production result. Before we move on to explore how the modellers tried to make sense of this confusing production, I will add a pinch of historical- and organisational context to the situational impression of the factory's operational reality, that we have gained through this chapter. The aim is thereby to add some contextual information about the factory's transformation as a work place. Another aim is to provide a more elaborated before picture, which enables us to better reflect on the changes, that we can see the involvement of the regulation project to have generated.

A Production under Transformation

The production machinery at Daka´ factories was generally very old technology, and many of the machines were developed for different applications that those they serve at Daka. For instance the coagulator or "thermo screw" as it is called at the factory, was originally made for heating ingredients for food production, rather than heating for separating animal waste products –as it was deployed at Daka. Much of the process machinery originally were for manually operation – meaning that human operators had to start, stop and adjust them during operation. Because this heavily reluctance on human labour was too inefficient, Daka started to automatize their factories way before the regulation project. The intention was already then to make the production less dependent on human operators. In the factory management´s own words, the utmost goal of the automation project was that: "Ideally the production will only need a green and a red button" (The production manager). In the management's view the ideal production would only need a start button and a stop button. This ideal was often expressed and shared among the management at Daka who intended to minimise the amount of human labour needed for the factory´s production to run. Additionally, the automation was also intended to minimise the "human influence" of the operators on the production –meaning that the human operators were seen as a liability to the efficiency of the production. To comprehend how far the factory and its workers had moved in terms of automation, I will shortly describe two operational states of production; one before the automation project; and one at the stage where I came to know the factory through the regulation project. In order to portray some of the most important differences between these two states of the production, my description will focus on the transformation of the operators work. The operator-staff was responsible for the continual operation of the factory´s production. Understanding their work is therefore central in order to grasp how the factory worked.

Pre-automation Organisation of Work

Only a few years back, when the factory had not yet been transformed-/reorganised through automation, four operational domains made up its physical production layout. These production domains were; (1) raw product reception hereunder, grinding, heating, and mechanical separation into solids and fluid by pressing the raw product, (2) separation of the solids and the fluids form the press; respectively through heat-drying of the solids, and through mechanical decantation and drier steam driven concentration for the fluids, (3) pressurised sterilisation and milling of the solids from the driers, and (4) packing, and storing in heated tanks (fluid raw fat) and big bags (solid bone meal).

Housed inside four separate factory floors, inter-connected through the factory´s infrastructure of transport systems, each of these production domains was under the responsibility of a dedicated operator. Working among the machines, observing their operation through their dissipation of noise, smells, and the product passing through them, the operators had a relation to the machines that was based on direct physical contact. At the pre-automation state of the production, operation thereby relied on the operators being physically present to the various machines in their domain of responsibility. Working adjacent to the machines, the operators could collect sensory perceptions of the production alongside inputs from sensors that was build into the machines. Handles and switches on, or nearby, the machines enabled the operators to conduct operational adjustments. The factory infrastructure, supporting the machines through various flows, also intra-connected machines inside factory floors e.g. by supplying them with electricity, superheated steam, and various states of the processed product. Besides adjusting machine settings, much of the control and maintenance of the production was conducted through manually regulating the flows entering, leaving, and passing through the machines.

Knowledge at work in the pre-automated production

Working in separated factory floors, the operators had little knowledge about the production outside their own domain. The knowledge that the operators relied on was mostly collected directly from the machines that inhabited the operators´ separated working environments. Training of new operators was based on apprenticeship where one experienced operator passed on knowhow and experience onto the apprentice. Because the operators who taught the apprentices did so based on their individual interpretation of the best possible operation of their domains, these apprenticeships passed on personal and local knowhow about how to operate the machines. The operators thus relied on knowledge that was mostly individual, local, and specific to their respective machines, handles and switches that they operated in their factory floors. The distribution of different production tasks between the various production domains also meant that the operators had to perform different work and conduct it under dissimilar conditions. Working in separate factory floors and having only little transversal communication, the operators often worked their domains through very different ideas about how the run the production best.

An example of these differences was clearly expressed between the raw product reception domain and the drier domain. The usual working principle as the deployed in the raw product reception, was to process the raw product as soon as it was received, and process it as fast as possible in order to avoid that the raw product, being a mix of pig entrails, bones, skin, and soft tissue, deteriorated. The various mechanical- and heating- based separation processes that received the product after the raw product reception, however depended heavily on the condition of the product and the quality of the separation. Efficient separation of the product strongly relied on it being sufficiently heated and pressed to have as much fat liquidized and squeezed out with the water as possible. Water that entered the driers was highly energy consuming to vaporise. Additionally the fat that did not run off as fluid would eventually become bone meal instead of the much more profitable raw fat. Where the raw product reception operated after a quantity rationale, that was constrained by the varying quality of the raw product, and how the production machinery coped with these qualities, the separation processes of the drier- and concentrator domain, instead depended on how well the product was processed. By contrast, we can see this as a quality rationale. These two production domains were thereby operated through different modi operandi, which more than often conflicted, because the means to reach large production quantities in one domain degraded the conditions for the following domain to achieve separation quality. The operators mentioned these conflicts as they were like the production domains waged war on each other. The way these domains worked against each other was thereby problematical in terms of coordinating the transversal production –not to mention transversal process optimisation.

Automation – Rearranging Work and Information

By automatizing the factory, the production was operationally reconfigured by establishing a new online information infrastructure that collected the process data from all the production machinery. This compilation of online machine data made it possible to install dedicated Programmable Logic Controllers (PLCs) that could take over much of the machines´ operation. Large parts of the manual operation was thereby displaced form the operators and onto the programmable controllers. The installation of the PLCs was thereby an important part of making the production less dependent on human operators. Alongside the PLC-based operation of the factory´s machines, the newly established information infrastructure also provided for another fundamental change of the factory’s operation. By taking out data from all the machines and collecting it for display on the screens in a newly built control room, the automation project also provided for a more unified production interface for the operators. Watching data representations of their respective production processes on computer screens enabled the operators to sit next to each other in the same control room. What the automation project brought to the factory, through the new information infrastructure, was thus to enable the operators to observe their machines at greater distances, to thereby gain greater proximity to their human colleagues who were responsible for the adjacent production domains.

Besides the technical advancement of further freeing the production from human interaction, the technological project of automating the factory production had also brought the factory a new centralised control room. By collecting, juxtaposing, and visually representing the entire factory´s production through process data, the control room functioned as what Latour (1987) termed a centre of calculation and likewise established conditions for a more powerful collectively distributed intelligence. Bringing together the operators and their respective responsibilities, along with visual representations of their production domains in the same room and on adjacent flat screens, provided the operators with a greater overview of their own production domain as well as those of their colleagues. This proximity enabled the operators to communicate face to face while sharing a visual perception of the entire production. In this new shared environment, the operators could better inform each other about the condition of their respective production domains –and if they conducted operations that would generate effects into the others´ production domains.

Redistribution of Responsibilities

The new information infrastructure in the automated factory thus rearranged the operators' work by releasing them from some of the practical tasks related to the online and locally bound operation of the machines. Practical tasks that before relied on the human operators were now translated into automated tasks that were handled online through the visual interface from the new control room. An implication of rearrangement thus meant that the work of the operators was displaced from several separated localities into one shared room. From the detached and separated operational domains that were close to their production machinery, the operators were now spatially displaced into a shared control room from where they connected to their machinery through online process data and automated process steering. The new control room had thereby entirely transformed the operators' previously separated and machine hardware based work environments into a collectively shared and data re-presentation based reality. While these changes displaced the operators´ workspaces onto a shared one, they also transformed their responsibilities. What before was four separated domains covered by four physically separated operators, were now reorganised into only three domains and distributed between the three operators. The operators' production responsibilities thereby went from being isolated to their respective factory floors, to instead cover slightly wider production domains.

The accumulation of information, operators, and their responsibilities into the same control room attracted additional tasks and responsibilities to the control room. All transport to and from the factory was controlled and coordinated through the control room. When machinery at the factory was to be repaired or serviced, the permission to do so was given, recorded, and coordinated from the control room. These new responsibilities translated the control room into being the operational command centre responsible for the majority of the factory. The operators´ work had thus changed in character to include communication- and coordination- activities; both transversally between their respective production domains; and with internal and external workers such as craftsmen and truckers who frequently had to visit the production. The operators' work was thereby transformed from individual machine operation to be more akin to production management. The transformation of the operators´ work thereby not only meant enhanced transversal collaboration across their production domains, but also enhanced coordination with other staff groups inside an outside the factory. The operators themselves reported this as a generative effect during our conversations. The new control room had physically displaced the operators, from plural localities close to their respective machines into one unified locality. The new control room had thus transformed the factory through a reorganisation that gave the operators a more central role by tying them closer together into one shared space. A shared space that also related the operators to other work groups and to new responsibilities.

Figure 5.10: Organisation of repair forms for visiting craftsmen. Photo by the Author 2011.

During the automation of the factory, the crew of technical consultants who conducted the automation also worked from the new control room. Much of the automation was thereby conducted from a temporary working station inside the control room. From this working station the PLC data blogs were written and adjusted by automation consultants to make the PLCs support the intended online operation of the production machinery. It was also through this access to writing machine instructions, that the regulation project later could integrate and test their regulation solutions on the factory´s production during they were developed. The regulation project thus relied on the same information infrastructure that was established by the automation project that preceded it at the factory. This information infrastructure would also provide the majority of the production data that the regulation project was to use for developing its regulation solutions. It was through the technical automation consultants, that the regulation project extracted production data from the information infrastructure's data storage. The control room was thereby also the access point through which the regulation project accessed to the bulk of recorded sensory data they deployed for their modelling. In the next chapter we will trace this data to the theoretical physicists to explore how they transformed what they knew of the factory in order to align it with physical knowledge about the world.

Chapter Six

From a Body of Information to Mathematical Models

The Construction of Representative Mathematical Models

The focus of this chapter is to look into the practice of simulation modelling. The specific type of simulation modelling that I investigate is called representative modelling. The notion `representative´ indicates that this type of modelling is about constructing mathematical re-presentations of phenomena that typically but not always are of a physical nature. Representative mathematical modelling can in this view be seen as a practice that produces mathematical re-presentations of phenomena. One of the performative gains of mathematical re-presentations is that they can be programmed onto computers where they can be processes and simulated. My interest in the regulation project's modelling therefore both concerns what was achieved by translating the factory's machinery into mathematics, and what was achieved by materialising mathematical re-presentations onto hardware. This chapter will however focus on the modellers' translation of physical machine processes into mathematics and how we can understand the epistemological dynamics of their practice. Principally we can see the construction of mathematical models as similar to the construction of an explanation where the model is made into an element that explains other elements.

[…] first we have to define explanation. In its simplest form […] it means establishing some sort of relation between two lists, one comprising an inventory of elements to be explained (B) and the other a repertoire of elements said to provide the explanation (A). (Latour, 1988 p. 157)

Following the idea that modelling is a variety of explanation construction, its true powers as an explanation does according to Latour depend on how many elements that the model can explain – and how well the model enables acting upon these elements at a distance. In the regulation project this means that the power of the mathematical models rely on how well they explain what is important to control through regulation. In other words, how much better the production machinery is held when holding the models. The power of the models thereby depends on how well they are connected to what they represent.

The work associated with connecting a model (an explanation) to what it represents (the elements to be explained), can be described as following two directional flows. One that goes from the machines at the factory to the modellers, and another that goes from the models and back to the machines. What has been mobilized from the factory hall and the machines that can stand the trip to the modellers is by Latour (1987) called immutable mobiles and information (Latour, 1988). In the previous chapter we saw how the modellers engaged with collecting and extracting information and data about the production processes at the factory. This chapter will follow this information by trace how the modellers make sense of it by constructing mathematical re-presentations of the machine processes. The next chapter (chapter 6) will describe how such mathematical re-presentations are made to return and integrate into to a production site in order to act upon its machinery. The intention with this chapter is to render a micro-level depiction of how the modellers built their models. The idea is to lift the lid on the black box of mathematical modelling by providing insight on some of the central epistemic mechanisms that were at work in the modellers practice.

Setting the Stage

Figure 6.1: Alsion centre hall in the early fall 2011. Sønderborg city is seen in the background. Picture taken by Author, 2011.

As part of my ethnographical fieldwork I conducted an observation study of the representative modellers everyday work at MCI. Most of the representative modellers in the regulation project were theoretical physicists. My observation study supplemented the data I collected from my participation in the modelling meetings. I studied the modellers' practices at the new Alsion research complex in Sønderborg, Denmark (see figure 6.1). The modellers' offices were housed around an U-shaped hallway at the top floor of the Alsion research complex. My goal was to get a hold of the modellers' everyday work by participating in their activities. One of my main empirical entries to the theoretical physicists' mathematical modelling was by participating in their modelling meetings. Although the meetings represented only a small percentage of the modellers' working time, they re-presented the pinnacle of the knowledge the modellers had gathered and put together during their individual activities. During the meetings, the modellers had to formalise and present their individual results and ideas. This was a prerequisite for the modellers' ability to share and draw upon each other's work during the modelling meetings. It was my intention to get as close as possible to what the modellers did, in order to obtain information about the bulk of work that surrounded their modelling meetings. The meetings only made up a small fraction of the modellers' work. Information about the modellers' everyday work was thereby important for understanding their broader practices and how their modelling progressed between the meetings. What the modellers could put forth and discuss during their meetings and what they thereafter could do to the outputs of these meetings, heavily depended on the individual and much less formal work they conducted between the meetings. These individual activities were for instance writing on paper drafts and reports. The modellers also spent a lot of time on computer coding and debugging and sourcing information in relation to what they modelled. This could be theoretical physics from academic journals and books, or specific data that could be relevant to what they were modelling. My first hand observations of the modellers' individual work and my meeting participation therefore constitute two different empirical sources that each provides different insight to modelling practice.

Another of my empirical entries was to conduct a full week study where I closely followed two modellers and participated in their day-to-day activities. Most of their work activities played out in their individual offices and in front of their computers. I also saw how they shifted between different tasks; some modelling related and some not. From time to time the modellers also arranged small informal meetings to discuss their recent results or how to get on from a dead end in their work. Being part of a research institute at a university, the modellers also had teaching and supervision activities. Here they disseminated knowledge to students. The knowledge that the modellers practiced through their hands-on modelling activities at their computer screens, thereby accumulated into the model that they were working on. Through these models the knowledge went on to the end receivers of those models or of their computed outputs. These knowledge flows streamed out of the university building, either into other academic environments when in the shape of academic writings such as papers and conference proceedings. Or into industrial settings through industrial cooperation as with the regulation project that had brought my field study to the MCI.

The knowledge flows that can be associated with the modellers' practices can in this perspective be understood to disseminate knowledge either internally or externally. Internally typically meant to other staff members when at an early and less "matured" stages –like in the cases of the meetings that I will look into shortly hereafter. When more matured and at later stages, knowledge were also shared to university students through teaching and tutoring activities. Externally the knowledge can go to peers in other academic settings who value either the added value of a specific application of the mathematics on a physical problem or the addition of an improved mathematical understanding of a class of phenomena. The interest of industrial receivers is generally either to be able to optimize something that they already do, or to be able to do something new. In industry the knowledge output is basically valued according to how it can be realised materially into production and thereby into market. In terms of a mathematical model, it is valued for it´s ability to act upon what it is intended to explain.

Some of the models that the modellers worked on would become part of multitudes of knowledge flows. In the case of the thermo screw model it was both disseminated into the industry through the regulation project, and into academia in the shape of a conference proceeding. Modelling is therefore not a knowledge activity that necessarily produces for only one well-defined audience. Instead modelling makes more sense as an activity that is characterized through what it does to its inputs, and what results it generates.

Representative Modelling

At the face of computer modelling it could seem similar to computer programming. Most of the time is spend on debugging sequences of computer code in order to make it behave as is intended. According to the modellers at MCI, a survey showed that around 90 % of their work was taken up by debugging related activities. Computer modelling however has different outsets and goals than computer programming and can rather be understood to incorporate programming activities as part of its method.

The outcome of modelling can in some cases be a computer program or a specific configuration of an existing type of computer program. But what goes into the process of constructing a model, deviates from most programming practices by consisting of data that are less processed and interests that typically are less defined and articulated. Computer modelling has typically been described as a practice that connects data with theory (Sismondo, 1999; Winsberg, 1999).

Figure 6. 2: A theoretical physicist at his office debugging a model after transferring it to a new version of the program. Picture taken by Author, 2011.

The role of the modellers in the regulation project was to develop the representative models of the factory's production machinery. Like we saw in the previous chapter, the available data and information from the factory had limited applicability to the modellers. While there were large quantities of data, most of this data only referred to what entered then machines and what left them. These input- and output data said little to nothing about what happened inside the machinery. In this sense we can see the machines' internal workings as a "black box" (Latour & Woolgar, 1979/86). Additionally, the recorded data at the factory was not the most reliable data because they were obtained under harsh conditions and were practically impossible to verify. However these were the conditions, and the theoretical physicists' job was to develop re-presentations of the machines that enabled the project to make better regulation models. In this view we can see the modelling at MCI to only have sparse knowledge and data about the internal workings of the machinery for they modelled. The modellers' intended role in the regulation project was to deploy their physics knowhow in order to develop a better understanding of how the factory's machine processes worked. Ultimately from the viewpoint of any modeller, the more raw data they can use to develop and test their model, the better. Had there been vast amounts of available raw data to produce a comprehensive re-presentation of the machines' internal workings, one modeller mentioned what he called "phenomenological modelling" as a possibility. By a phenomenological model, he meant that an analysis of the different raw data variables could establish statistical correlations between the different data parameters. However in the case of the regulation project, as in most other cases of mathematical modelling, the available data was sparse. Which also was the reason for including the representative modellers. The factory and the regulation project wanted to know more about how their machines' process variables could be understood to depend on each other.

The output of the modelling practice in this case was to support and improve regulation of the machinery. While the theoretical physicists developed representative models that re-presented the machines, the ultimate goal was to integrate these re-presentations into operational regulators that could improve machine operation. The knowledge that the modellers developed was thereby to be implemented as part of the regulation technology controlling the machines. In terms of what goes in and what comes out of the modelling process treated in this chapter, the modelling can be understood to translate general physics-knowhow about a variety of physically defined phenomena together with sparse knowledge and data about a machinated sub process, into mathematical representation for regulation purposes of that machination. The question that this chapter will approach is how the modellers transformed generalised physical knowledge and sparse data and knowledge about machinated processes into mathematical re-presentations with explanatory powers over these processes. This question will be addressed through two cases based on empirical material collected during my participation in three meetings that concerned the modelling of the drier machine during a period of 7 months. The three modelling meetings illustrate different stages of the modelling process. The cases thereby span from the very early activities of choosing and delimitating what to model, to the more mathematically realising stages of the modelling process.

The first modelling meeting was at a very early and “conceptual” stage of the representative modelling process. The following meeting was at a more mathematically substantiated descriptive stage.

Paying close attention to what the modellers did and to what they modelled and how they changed it into something different and what thereby was gained or “amplified”, is my approach to describe the modellers’ practice and what was special about its way of handling knowledge. In order to do this I use the conversation between the modellers during their meetings as the structuring outset for analysing how they constructed their models step by step. This detailed depiction of the modelling process also provides information on what we can understand the models to be at their different development stages. An important element of the modellers’ conversations was their “non-verbal” visual language. The visual re-presentations the modellers produced during their conversations can be seen as important material knowledge artefacts (Knuuttila & Voutilainen, 2003). The use of visual re-presentations is therefore included to my account of the modellers’ model-building conversations.

Translating Information – Early modelling meeting

The activity that is to be described in the following analysis is a meeting between three modellers. Together the modellers formed the working group of the regulation project who had the responsibility for developing the mathematical models describing the sub processes at the factory. The time at which this meeting took place was in the early fall 2011. The meeting followed the modelling of the thermal screw that the modellers had been working on during the summer. The main topic of the meeting was to discuss which sub process at the factory that they were to model next, and how they should go about modelling it. On the picture (in figure 6.3) a modeller is seen pointing to an illustration on the white board during the early modelling meeting.

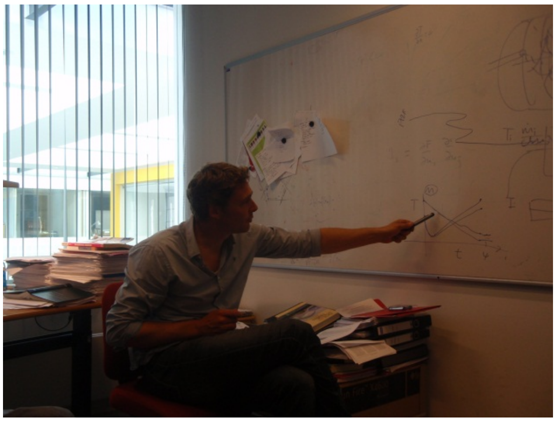


Figure 6.1: Modeller explaining the principle in water evaporation from meat particle by pointing at his drawing on the white board. Picture taken by Author, 2011.

The meeting has been chosen as an example of the activities that the modellers do in a very early stage of a modelling process. Examining this early work brings us closer to how the modellers take their first steps in constructing a re-presentation of a phenomenon. Through the modelling process this re-presentation, which is seen on the white board, will be translated into a more recognisable mathematical model at later stages. The selected parts of the conversational activity among the modellers have been selected from the entire conversation to provide both a comprehension of the continual process, and the different steps that the modellers go through. The participants in this meeting all spoke Danish and the following quotations have been transcribed in Danish and translated into English.

Which Phenomenon to Re-Present

The meeting took place at one of the modellers´ office. While informally knocking on the door and asking whether it was now they were to meet, one of the other modellers came in. The modellers started talking about which sub process that they should begin to model. They brought up the plate drier and the condenser as two potential objects to model. The drier and the condenser are both known to be very energy demanding sub-processes at the factory and each make up a significant contribution to the total energy consumption of the factory. Discussing the condenser, the modellers soon arrived at an agreement that they knew too little about how it worked. Instead they continued with the plate drier about the same time as the last modeller knocked on the door and snuck in to the meeting.

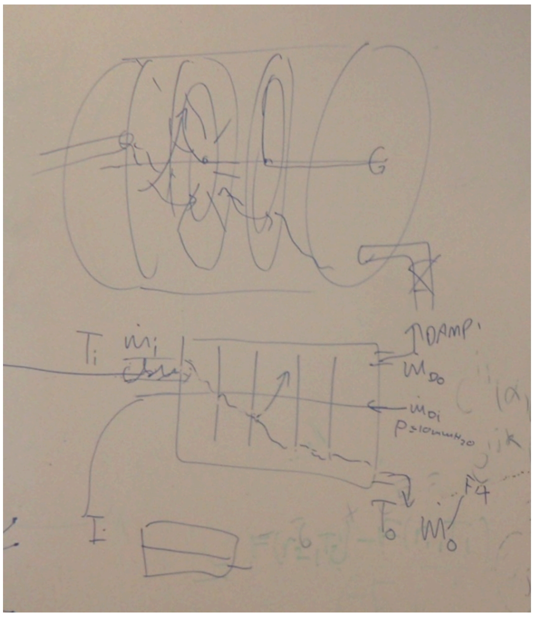


Figure 6.2: 3D and 2D principle of the drier as representations took shape during the meeting. Picture taken by Author. Modelling meeting fall, 2011.

Having in one hand the process description report describing all the machines and sub processes at the factory, the modeller from the previous picture sketched the three dimensional working principle of the plate drier see in the picture (figure 6.4). Sitting next to the white board the modeller projected the qualitative description and production data on the plate drier from the paper in his hand onto the white surface. Taking up most of the wall next to the modellers in the small office, the white board transformed the sketch of the plate drier into a pivotal entity around which the meeting to place. Supporting the 3D sketch a two dimensional sketch of the drier was made beneath it to which was added operational parameters such as Ti, mi, Md1, Tdamp (Temperature of steam), Md, T0, and M0.

Though the document in the modeller´s hand contained important information about what the plate drier does to the product that goes through it, it´s production data, how it is operated, it´s measured working parameters at the factory, its energy efficiency and potential savings and increase in production, the document did only supply sparse information on *how* the plate drier processes passes through and dries the product. What was thereby done, by sketching the plate drier on the white board, was not limited to visually project the content of the document onto the larger surface. The modellers pulled on other sources of information, extracting, merging, and condensing what they had seen and perceived at their visit to the factory half a year before. Together with their experiences from modelling other industrial equipment, the modellers drew together all these inputs synthesizing them into the conceptual sketches on the white board as seen in figure 6.4. In other words, the modellers materialized an educated guess about the plate drier´s working principle based on what they knew at that time.

TRANSLATION: **INFORMATION → RE-PRESENTATION**

When the modeller at the white board leaned back in his chair leaving the whiteboard with the two drawings, one of the other modellers responded conformingly to the drawings on the white board as he said:

"This is probably also the picture that we have gotten on the board now; that the plate drier actually combines a tank where it is fed with some mass in on the one side, and then some plates that rotate, but rotate without helping to press the material through."

The modeller thereby highlighted a number of details about how the modellers, in terms of their sketch, understood the plate drier machine. For the analytical purpose of being able to assess what the modellers do and how they do it, I will make a distinction between how they account for different attributes of the drier as either a material – *object* – or as something that it does; a – *function –.*

What the modellers talk about when they discuss the drier machine can thereby be divided into its material dimension being the bits and pieces that it consists of, – *objects* – so to speak, and into its functional dimension being what the machine and those bits and pieces do; their – *function –.* The following analysis will on the basis of this distinction account for how the modellers can be understood to differentiate between – *object* – and – *function* – to make explicit what the modellers mean during their conversation. The distinction thereby helps to qualify how the modellers relate to what they model by clarifying patterns in their modelling activities.

In this view, the modellers can from the above quote be understood to account for the drier as an – *object* – that in principle works like a big tank that is fed with `mass´ from one side – *a function –.* It features rotating plates, which are – *objects* – that contribute to define the material dimension of the drier at a sublevel. About the specific – *function* – of these rotating plates, the modeller said that they do not help transportation of material through the drier which accounts for a relation (or in this case suggested lack of) between the plate – *object* – and the transportation – *function* – of material which is another – *object –.* The – *function* – of one – *object* – can thereby be understood to condition something about the – *behaviour* – of another – *object* – which in this case is the `mass´ by which the modellers mean the "product" that moves through the drier.

From this it can be noted that the modellers also treat the `relation´ between – *object* – and – *function* – in their rendering of the drier machine. This is interesting because the relation between these two dimensions of the machine implies the potential to speak of one through the other. In relation to Latour's definition of an explanation, the modellers can here be understood to establish relations between elements on two separate lists; the plate drier machine which is seen as consisting of the objects "tank" and "plates" that by the modellers are related to its function, which they simplistically portrayed as transporting material through its body – here referred to as the "tank" by the modeller.

For the sake of analytical transparency I will briefly clarify the intended meanings and relations between – *objects* – and – *functions –.* In addition to these I have also developed/introduced a third notion that I call – *behaviour –.* I have developed the three notions; *object, behaviour,* and *function* to analyse the conversation of the modellers during their meetings. I will also describe how these three notions relate one another, as well as the meanings that these relations can be understood to account for regarding how the modellers discuss their modelling of the drier machine. The three notions are thus to be understood as analytical tools that enables us to better understand how the modellers condition their knowledge practice. These notions are intended to help us with tracing how the modellers identified and listed re-presentations of "known" objects from the machine processes; and how they transformed these known objects in order to connect them with new re-presentations that belonged to another list of generalised knowledge about the physical world. The notions are in this way intended as means for interpreting how the modellers realised what they believed to be the most adequate natural scientific causes *behind* the machines' operation. We can thereby see these notions as a method to depict how the modellers organised and settled re-presentational controversies about what natural causes they deemed to govern the machines' behaviours. While the modellers' job was to speak about the machines on behalf of Nature, these notions will help us to see how the modellers manipulated both existing knowledge of the machines and existing knowledge about the physical World, in order to speak through their representative machine models with explanatory authority.

Objects

With the category of – objects – I refer to the way that the modellers introduced the material entities that they identified from the target system into their analysis. My choice of the notion of "objects" can be referred to Heidegger's distinction between things and objects (Knorr-Cetina, 2001). Whereas "things" denote complexity, multiplicity and history, "objects" instead signify a "lack in completeness of being that takes away much of the wholeness, solidity, and the thing-like character they have in our everyday conception." (Knorr-Cetina, 2001 p. 190). Another use of "objects" is that of Bucciarelli (1994), where he uses "objects" to describe the physical entities that makes up the professional "object worlds" in which engineers work. Both Knorr-Cetina's and Bucciarelli's uses of the notion of "object" can be interpreted as familiar with the notion of "re-presentation" because they refer to "objects of knowledge" (Knorr-Cetina, 2001) that connects professionals to what they work with (Bucciarelli, 1994). My definition of "objects" is however more restricted because my intention is to use it for spelling out characteristic differences to other types of re-presentations. An – *object* – in this analysis is thereby to be understood as a re-presentation of an empirical entity in its *material* sense. It can be a machine part, a functional group of machine parts, or the product that goes through the machine. Being an object means that the entity often is described through its physical properties e.g. its physical dimensions and material related properties such as: mass, stiffness coefficient, conductivity and storage capacity of heat and electricity. What are visible and statically measurable are objects. Objects can thereby serve as material reference for knowledge processes (Latour, 1999; Carlile, 2002; Bucciarelli, 1994; Star & Griesemer, 1989). In terms of the potential role of – *objects* – in an explanation, they connect to the list of "known elements" that are at one hand to be explained, and at the other hand the premise for establishing connection between the domain of the "known" and that of "knowing" in an explanation.

Objects are understood to relate to other objects that they are physically connected to. Objects and their physical properties thereby condition each other through the way they are connected. The dynamic properties of an – *object* – is conditioned by how it is configured through its relations to other objects and can be detected as it´s observed – *behaviour* – such as movement, temperature, or other variations.

An – *object* – can be referred to both as something that acts, or something that is acted upon. In grammar we know this distinction through the notions of "who" and "whom", where "who" refers to acting "subjects" and "whom to passive "objects" that is acted upon. This distinction helps to make clear the different types of relations that the modellers make to the objects they treat. It is important to note that where the philosophical tradition of representationalism would lead us to believe that there should be a "natural" distinction between the domain of the subject and that of the objects, ANT and generalised symmetry instead rejects that dichotomy and proposes that both humans and things are constituted by their network of relations (Callon & Latour, 1992, Latour, 1991/1993, Latour, 1999). Building on this principle our analysis can thus recognise the distinction between objects that act and objects that are acted upon as constructs of the networks of relations that they are placed within. Referring to an – *object* – as something with agency thus emphasises it´s – *behaviour* – and with this, the object´s observable detectability and therefore potential reference to the phenomenon the object is part of. An example of this was for instance: "The product doesn´t do anything, it just goes through the system" – modeller during a modelling meeting. On the other hand, when referring to an – *object* – as something that re-acts to external agency, and therefore is acted upon –for instance when "It gets heated", relates the – *object* – to a – *function* – that conditions the object´s – *behaviour* –. The effect of this move is that the – *behaviour* – of the – *object* – is seen as a consequence of a – *function* – that is understood to be *behind* the object's behaviour. This – *function* – is in this way proposed to "explain" that – *behaviour –.*

Behaviour

When the modellers speak of an object's behaviour, in relation to external excitation, they see the behaviour as indicative for how the object is conditioned and configured by its relations to other objects. An ensemble of objects that condition and configure each other can thereby be seen to behave like a punctuated entity with collective response-patterns to external excitation. Machines are in this perspective such punctuated entities of objects that configure the behaviour of each other.

"The simplest means of transforming the juxtaposed set of allies into a whole that acts as one is to tie the assembled forces to one another, that is, to build a machine. A machine, as its name implies, is first of all, a machination, a stratagem, a kind of cunning, where borrowed forces keep one another in check so that none can fly apart from the group. This makes a machine different from a tool which is a single element held directly in the hand of a man or a woman." (Latour, 1987 p. 128-129)

The plate drier is a punctuated network of physical objects that together produced behavioural patterns to external inputs. Machines like the plate drier make up such collectives of physical objects, in which the specific conditional relations between the objects often are little understood, and their differentiated behavioural patterns practically inaccessible for observation. Machines like the plate drier were due to insufficient knowledge about it internal workings, treated as a `black box´ by the modellers. The machines' behaviours had to be assessed purely based on observations of their inputs and outputs. When the modellers zoomed in on the machines, it helped them to define sublevel objects that they understood the machines to consist of. When the modellers instead zoomed out, onto the production chain in which they understood the machines to conduct certain – functions –, it helped the modellers to contextualise what they knew about the machines.

The – *behaviour* – of – *objects* – can be seen as materially conditioned and therefore measurable through these material conditions. Observation of behaviour can therefore be seen as belonging to the "known" elements of an explanation. The possibly causes that are believed to be responsible for detectable behavioural patterns, instead belong to the elements of "knowing" and are in this analysis referred to what the modellers define as – *functions –.*

Function

Function can be seen as the performance of machination. Performance is often directed towards objects that are not part of the machination assembly itself. A function is therefore what conditions objects' behaviour. A function understood as what makes objects move, heat, cool, change state, or what other behaviours a machination is made to produce. Functions depend on objects. A function is realised by the collective behaviour of the objects that its machination consists of. Objects and functions therefore relate so that objects condition how functions operate. The effect of functions is the behaviour of objects. Functions are typically assessed through either the observable behaviour of the objects that they affect or through analysis of the objects that they are machinated of. Functions themselves are not directly empirically assessable which is why they have to be treated either through how they are materially conditioned; through the – *objects* – that they are made of, or through their observable effects which are the measurable – *behaviours* – of specific – *objects –.*

In the conceptual framework of an explanation a – *function* – is understood as a cause that is responsible for certain effects that are detectable as certain – *behaviour* – of – *objects –.* From the list of "knowing", functions therefore are intended to explain something about the elements from the list of "the known".

Objects to define Functions of a Phenomenon

After clarifying the analytical notions through which I will re-present the modellers' work, we will now continue the modelling meeting about the plate drier machine. While two modellers shortly discussed a further sublevel of physical attributes – *objects* – of the plates that could account for their contribution to the transportation – *function* – of material through the drier, the other modeller asked:

"Why are they [the plates] there?"

The answer sounded: *"To conduct heat"* – the last part: *"…duct heat"* was said by all three modellers at once.

"Not to transport" it was responded.

By what seems like collective reasoning, the modellers concluded that the primary – *function* – of the plates – *object* – in the drier was about conducting heat to the material that goes through the drier. They thereby related the plates as – *objects* – to heat conduction, which they thereby stated to be the – *function* – of the plates in the drier.

TRANSLATION: **OBJECT** (plates) → **(primary) FUNCTION**
= Heat conduction

"But they rotate" One modeller then stated about the plates to which another modeller suggested:

"… if it´s rotating plates then there could be some fins sticking out that helps to muzzle it [the material going through the drier] about."

While pointing at the plates on the 3D sketch (figure 6.5), the modeller responded that:
"I think that I have seen on these that there are some [fins]".

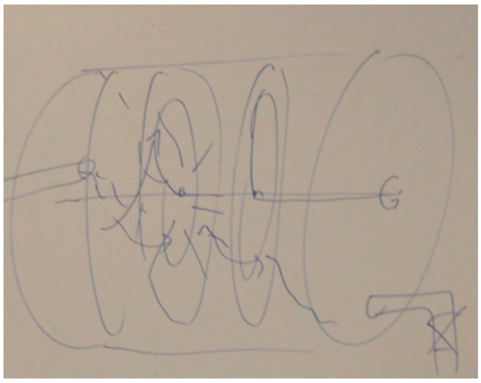


Figure 6.3: Zoom in on the 3D drier sketch. Picture taken by Author. Modelling meeting fall 2011.

Cautiously the proposed idea about the plates having fins was supported by memory of a six months old visual impression from looking down in an actual drier machine at the factory. Through memory of a visual impression the modeller connected the collective understanding of the plate drier on the white board with the plate drier machine at the factory. By adding small lines to the plates on their drier sketch, the fins were materialised herein. These additional technical features about the drier were in this way added as – objects – to their representation of their conception of the drier on the white board. The fins can be seen as the blue lines added to one of the circular plates in the three dimensional sketch in figure 6.4 and 6.5.

TRANSLATIONS: **INFORMATION →** (additional) **OBJECTs**

"*What is it that gets [the product] to be transported forward if [the plates] weren´t there?*"

By which a modeller diverted the focus away from the plates and instead towards thinking about the mechanism of transportation, which the modellers had just concluded was not the primary function of the plates. Through this questioning, the attention was moved away from the plates as – objects – toward the transportation – function – and the cause behind this function.

"Yes, just exactly"

Was a modeller´s response supporting the shift in focus from – object – to – function – implied by the other modeller´s question. Pointing at the mechanism that fed the drier with material at the white board the modeller continued:

"Of course, when that screw keeps feeding a mass in then it has to push it out in some way. Somehow if there isn´t a mechanism then one must just have to imagine that it is pushed out on top, so there is something that stays inside the system, so there must be some kind of transport mechanism?"

Through this statement the feeding mechanism was related to the transportation – function –. It was proposed that pushing material into the drier was the cause responsible for moving forward the material inside the machine.

TRANSLATION: **OBJECT** -//> **FUNCTION**

(New) **OBJECT →** (New) **FUNCTION**

Furthermore this simple mechanism of the inlet pushing the material through the drier was also problematized. Due to a suggested behaviour of the material that was assumed to be linked to the proposed transportation function, it was argued that some material inevitable would stay inside the drier. This was used as an argument for the likely existence of another mechanism causing the transportation – *function* –. The feeding mechanism was hereby included as an – *object* – and related to the transportation – *function* – though the feeding mechanism that was also suggested to not sufficiently account for the transportation. The argument thus lead to suggesting the existence of another – object – that on the other hand would be able to account for the transportation – *function* –. The relation between function and object was thereby used to move from one object to another – an object, which at that time was not finally determined yet. To this a modeller responded:

"The most important [function] is probably the heat conduction, as you say for the plates, and then that there comes mass in does that mass has to get out again, so isn´t it most likely that [heat conduction] is the most important function, [...] could one then not just replace that with an effective heat conduction?"

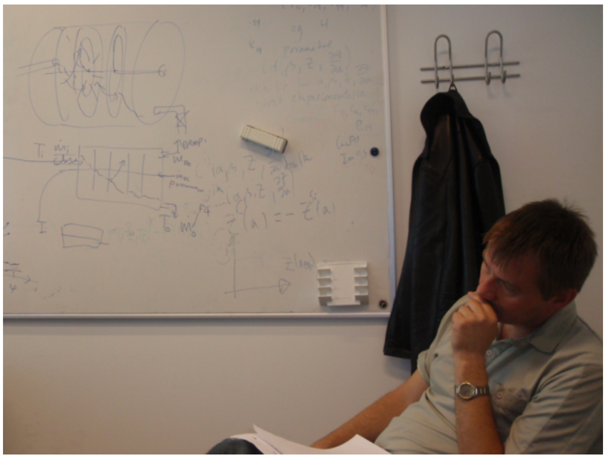


Figure 6.4: White board with sketches of the drier that slowly takes mathematical shape by including representations of chosen functions. Picture taken by Author. Modelling meeting fall 2011.

Building on what the other modeller had just said, as a, for the time being, for the modellers, adequate answer to the question about the mechanism behind the transport function of material through the drier. This modeller used the proposed transportation mechanism to get on to another – *function –;* the heat conduction, which was suggested to be `likely´ the most important – function –. Interestingly, it was also suggested in the statement to `replace´ the heat conduction function with `effective heat conduction´. By this the modeller meant to re-present the function of heat conduction through a mathematical expression of the physical theory for effective heat conduction.

TRANSLATION: (primary) **FUNCTION → PHYSICAL THEORY**
(Heat conduction) → (Mathematical expression)

The interesting turning point, illustrated here, was a shift in focus from the machines' function(s) of interest onto a function´s possible mathematical representation. Adding the mathematical representation as an explanation to the sketch on the white board gave shape to the drawing´s conceptual mathematical dimension. The sketch on the white board, which during the meeting was the current state of the model of the drier, thus took an important step towards becoming a *mathematical* model of the drier.

To better grasp how the modellers were able to make this translation of some trait of the drier machine at the factory into a mathematical re-presentation, let us try to recapture what they actually did during the meeting.

Changing between Objects and their Functions

In order to unravel the ways of the modellers, we have to look at what they did from choosing an object to model, to when they arrived at a very first mathematical translation of the physical machine. Though we during this meeting have not seen anything decisive yet with regards to the mathematical model that the modellers are building, we have witnessed how the modellers shifted about between ways to represent information and explanations concerning the drier machine. Analysing the modellers´ conversational activity into a material *object*-dimension and a *functional*-dimension has shown the modellers to manoeuvre between these two ways to re-present the machine.

The overall move that can be recognized as significant for understanding what the modellers did, was that they took departure in the material object-domain, in this case the drier machine and its plates, and then defined the related function that they found most important –which in this case turned out to be heat conduction. This function was then exchanged with a mathematical expression that the modellers believed could adequately describe that physical behaviour of the machine. In this case we witnessed how an important aspect of the plate drier machine was defined through the expression for effective heat conduction.

TRANSLATIONS:	**INFORMATION**	**→ OBEJCTS**
	OBJECTS	**→ FUNCTIONS**
	FUNCTION	**→ MATHEMATICAL FUNCTION**

Besides boiling down this preliminary stage of the modelling process as the move from choosing central material attributes of the machine to defining their functions for then to exchange these functions with mathematically described functions, the meeting also provided us with some insight to the shop floor work of the modellers´ reasoning at this stage of modelling. In order to get a better grasp of the modellers' reasoning, we need to look closer into how they shifted about with the object dimension and the functional dimension, and what they gained by this.

Object-dimensional Activities

As we have seen, the modellers started in the object-dimension by first discussing which machine to model out of a variety of potential objects to model at the factory site. Staying within the object dimension, further delimitation of the chosen object was done by focussing on sublevel objects of the machine that appeared to be important. In this case, the modellers conducted further analysis of the plates inside the drier machine. These object-delimitating moves enabled the modellers to concretise what they looked at and how they understood the delimitated object. The modellers moved further down into the sublevels of the object dimension of the phenomenon they modelled by defining new objects at those levels. E.g. when the modellers introduced the fins on the plates.

An important aspect of these object-domain-activities was that the modellers included the white board re-presentations of the phenomenon they modelled as a kind of "master" re-presentation. During the meeting, the modellers continuously updated and refined their re-presentations by drawing additional objects, parameters, and mathematical notions onto them. The modellers thereby used their white board representations to organise, focus, and refocus their conversation as they looked for new objects in other parts of the machine.

The white board preserved what the modellers added to it and structured their ideas by visually relating the different objects to each other as they were fitted onto the sketch of the machine. This function of the white board was important for understanding how the modellers´ knowledge process during the meeting was conditioned in terms of the white board re-presentation's role. In line with what Star and Griesemer (1989) and Carlile (2002) defines as Boundary Objects, the white board sketches was shared between the modellers and contributed by establishing a shared context "that sits in the middle" (Star, 1989). The white board sketches can be understood to represent the model of the object at this early stage of the modelling process, being the modellers´ contemporary collated re-presentation of the drier machine. Collecting and organising what Latour calls information and inscriptions, the sketches on the white board already at this early stage began to emerge as what Latour (1987) terms a `centre of calculation´, drawing together objects that provided reference to the material machine at the factory.

Moves into the Functional-dimension

What the modellers did several times during the meeting was to switch focus from an object to the function of that object. This was something the modellers could be observed to do at all levels in the object-dimension by asking into why the object was there or what function it had. E.g. when it was asked why the plates were there. This move enabled the modellers to focus their attention on what the parts in the machine did, as part of the machine´s overall function. By doing this, the modellers then asked into the relationship between object and functions to explore the nature of this presumed relation. The modellers examined the cause of a function by either neglecting an object as the probable cause of a function, or by including other objects to examine their possible relation to the function. The modellers did both when they examined the transportation function by first neglecting the plates and then introducing the feeding mechanism.

The modellers also looked at the behaviour of objects in order to assess the functions conditioning that behaviour. This approach can be seen as a variation of removing and/or adding an object to the explanation of the behaviour of some object. Another variation of this approach was to suggest an object or function to cause the behaviour under examination in an unlikely way, and then look for what prevented this unlikely behaviour from happening. This is what the modellers did when suggesting that some material would stay inside the drier, if the feed of new material, was the only cause of the transportation. The modellers thereby implied the necessity for some other function to contribute to the transportation.

In this way the modellers drew out theoretical idealised functions from what they knew of the machines that they saw as compatible with theoretical physics. We can thereby understand the modellers to have reduced the complexity of the machine re-presentation in order to achieve compatibility with generalised knowledge about idealised physical systems. This can be seen to relate to what in the technical modelling literature is characterised as "standardisation" and "idealisation".

Functional delimitation and Mathematical Re-Presentation

Within the functional dimension, the modellers also delimitated what function(s) they worked on, as they delimitated objects within the object-dimension. One method that the modellers deployed for doing this was to shift focus from one function to another. Settling on a suggestion previously presented, as an adequate explanation for that function, the modellers could move focus onto another function that they recognised to be more important. The modellers performed this shift in focus from the transportation function to the heat conduction function, by accepting the feed as an adequate explanation for the transportation of product through the drier. This enabled the modellers to go back to the heat conduction that they regarded as more important.

Delimitating function(s) of interest within the functional-dimension enabled the modellers to concretise the functions that they understood to be the most significant causes explaining the phenomenon under exploration. Delimitating and defining the function(s) of interest enabled the modellers to become specific about what they had to represent through mathematics. In this way the modellers sought to delimitate what kind of physical function that they were to "simulate" with a mathematical function. Exchanging the function(s) of interest with mathematical functions can thereby be seen as the modellers' method for making the mathematical function an adequate representation of the delimitated function. In this way we can understand the modellers' to approach what they saw as an adequate mathematical explanation of the phenomenon. When adding the mathematical function re-presenting the heat conduction of the drier to the sketched model on the white board, the modellers took a crucial first step towards providing a mathematical dimension to the explanatory power of the model.

Regulation Advancements at the Factory

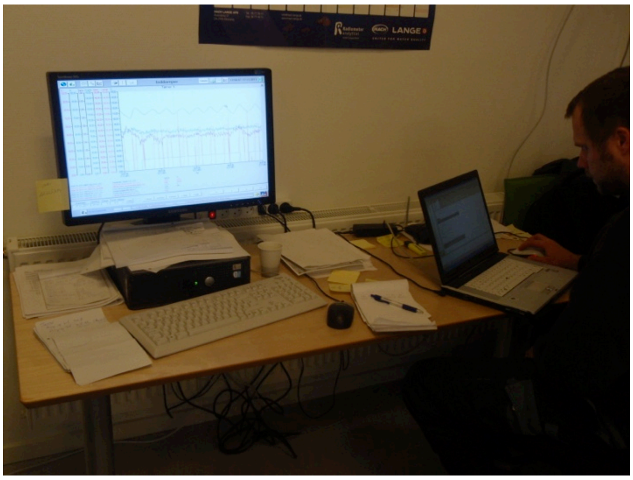


Figure 6.7: Picture of the automation workstation in the operator room at the factory while work was done on the drier steering. Picture taken by Author, fall 2011

Since the modelling meeting on the drier model in the early fall 2011, a variety of new initiatives had been implemented at the factory regarding the control of a drier machine and its temperature oscillation. These initiatives were conducted through the cooperation between the director of CORE and the factory in relation to the regulation project. Though the modellers were part of the broad collaboration on the energy efficiency project, their modelling activities were not part of these specific activities at the factory. There was, in other words, no direct connection between these energy efficiency initiatives at the factory and the still very incomplete and conceptual drier model under development at the modellers. That said, the practical initiatives at the factory generated experiences and produced new information and ideas that also reached the modellers through the regulation project cooperation.

In order to understand what had been achieved on some of the drier machines at the factory I will shortly describe the basic operation principle of these machines and the identified problem that the initiatives aimed to sort out. The drier machines are operated through two mechanisms. One takes out the heated and dried product when it exceeds a given temperature. The other mechanism is the feed of new wet product, which is to be dried. As the driers take in new product, heat is dissipated into the new and colder product. This means that some of the supplied steam condensates and contracts inside the plates, to release that heat energy. The condensation of steam gives space for new steam to enter the system. Traditionally this feed of product into the drier has been controlled by stopping the feed when the steam consumption reached a certain level and starting the feed again, when the steam consumption decreased to a level well below that at which the steam was shot off. By installing a regulation that controls the inlet of product to the drier so that the steam consumption is kept more stable and thus effectively higher in average, it showed to be possible to increase production throughput and thereby the total energy efficiency. Through this scheme of regulation, the driers consume more steam energy, but relative to the steam consumption, the driers output more dried product, which translates into less energy consumption per produced quantity of dried product. This was confirmed by controlled tests monitoring the driers' energy consumption and dried output mass over time to compare the new regulated operation with the baseline operation of the machines.

The initiative at the factory was to try out regulation ideas to diminish the temperature oscillations that occurred at the output of the drier. The steering method of the outlet was determined by the temperature measured on the product inside the driers next to their outlet hatch. When this temperature reached 112C, the product was formally approved as acceptably dried for food production, and the basic steering was allowed to activate the transport of product out of the drier. After the outlet transportation had been turned on, the temperature typically continued to increase for a while before it levelled out and started to decrease again. When the temperature dropped to 111C, the basic steering of the driers deactivated transportation of product out of the drier.

The basic steering of the driers was written as machine codes in the PLC blogs that were implemented back when the driers were automated. 111C was defined as the lowest acceptable temperature for the dried product. The set value was encoded into the basic steering and ensured that the driers lived up to the production line´s category 3 food approval requirements. These temperature thresholds were therefore not considered possible to adjust.

After stopping the transport out of the drier, the inside temperature typically remained decreasing for a while before it levelled and climbed again. This tendency meant that the temperature typically was oscillating in large variations around the specified values of 112C and 111C. Drier one, which was placed so that it was the first to receive the product from the press, also received most of liquid part of the product. Drier one was consequently the most exposed drier and therefore the machine that was most prone to great temperature variations. These were often in excess of 10 to 20C´s around the intended 111-112C. The typical temperature variations of drier one can be seen in figure 6.8.

The consequences of the driers´ temperature oscillations were that their outlets were paused for longer periods and that the temperature of the outlet often was much higher than what was necessary. Both of these factors contributed to decreased efficiency of the drier machines and increased energy consumption.

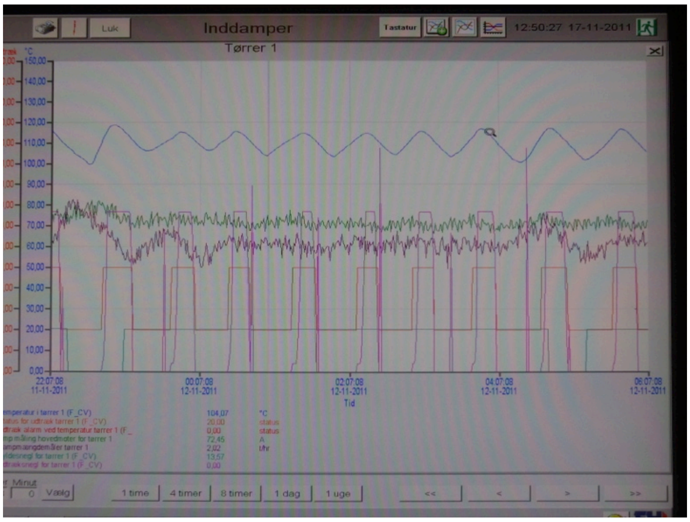


Figure 6.8: Close up of a screen monitoring drier one´s operation. The blue wave-like line at the top of the screen is the continuously measured temperature of the product inside the drier. The temperature variations are what the implementer calls to be "oscillating". Picture taken by Author, fall 2011.

The new regulation idea was intended to deal with the decreased efficiency through minimising the temperature oscillations at the outlet by starting and stopping the outlet *"out of phase to the oscillation"* as the implementer put it. The practical test of this idea was to displace the opening and the closing of the outlet relative to the temperature development. This meant opening the outlet when the temperature had just levelled and started to fall, instead of when it had dropped all the way to the 111C set point. The opening of the outlet under the new steering scheme started once the temperature began to rise, conditioned that the temperature was above the predefined 112C set point.

Figure 6.9: Temperature variations with and without the new "out of phase" steering. The left part of the plot shows the operation caused by the basic steering. The right part of the plot shows the effect of the new steering scheme. Picture taken by Author, fall 2011.

These recent experiences with the plate driers meant that the driers had gotten increased attention both among the management at the factory and in the regulation project. The modellers we are studying in this chapter had been in contact with the implementer who coordinated the regulation project and was deeply involved with the implementation during the time up to the meeting.

The effect of trying out the new steering scheme can be seen in figure 6.9. At this very early stage of testing this regulation idea, the actual testing was done by closely monitoring the temperature development, manually turning on and off the outlet transportation through the interface in the control room. As part of these testing activities, different operational parameters were tested to understand how they affected the temperature variations. The outlet speed of the transportation screw was one of the operational parameters that were tested to examine how the temperature oscillations responded to different screw speeds. A general challenge regarding these testes were uncontrollable variables that impacted the test was impossible to detect. The major of uncontrollable variables in the factory's production were the condition of the product throughout the production line. Producing reliable test results at the facility was therefore very difficult and a never-ending challenge.

Realising Theorems

Slightly less than two months after the first modelling meeting that initiated the modelling of the drier machine I was invited to participate in the follow-up meeting. The same three modellers from the former meeting participated with the addition of a new modeller who had since been employed to work specifically on the regulation project. The meeting now took place in a large room adjacent to the modeller´s office spaces at the top floor of the Alsion building. This room was intended for larger meetings and teaching smaller classes. We, the five participants, only took up a small part of the room in one end where two walls granted us with large black board surfaces. The reason for having this meeting was for the modellers to continue the work on the plate drier model and further develop it towards something that could explain how the drier machine operates.

The modellers' recognition of the recent advancements on the driers steering therefore have to be seen in the light that the modellers had not been physically at the factory during this process. The modellers´ primary source of information has been through the project coordinator, who briefed them through telephone calls and emails. Because the new modeller primarily spoke English the following meeting quotations are directly transcribed from the modellers' conversations English.

Connecting Functions and Theorems by Mathematical Re-Presentation

At my arrival, the meeting had already started and one of the modellers had sketched the plate drier on the black board. He mentioned that he had been on the telephone with the coordinator of the regulation project about the coordinator´s interest in their modelling of the drier machine. He also mentioned the coordinators' experiences with steering the drier out of phase in order to minimising the temperature fluctuations. The modeller then approached the black board to explain what they knew about the drier machine and the following conversation unfolded:

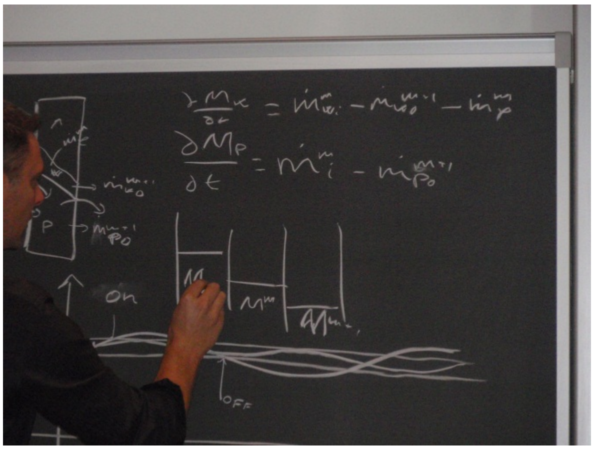


Figure 6.10: Modeller at the black board describing the mass flow in the plate drier. Picture taken by Author, fall 2011.

" [...] so this will give rise to the diffusion equation and then the diffusion constant will be the transport from this sector from here and to the next sector."

The basis of the discussion begins in the mathematics where the modeller explained the transport – *function* – of the product – *object* – as a diffusion equation with a diffusion constant that related to the transport from one sector of the drier to another. From the previous meeting this appears as a stark shift in the way that the modellers talked about the operation of the machine. Two months earlier the modellers primarily formulated their suggestions through more humble questions whereas the meeting now took off with the outset in more developed mathematical - *explanations* -. From the very beginning of the meeting, the subject of the mechanism behind the transportation of product through the drier was brought back as a central question for the modellers to settle.

Another modeller: *" Why do you call it diffusion? It´s flow isn´t it? –the first derivative... ...But basically you are now just formulating continuity equations, you don´t have to talk about the mechanism behind it."*

The modeller at the black board: *"This will end up in a diffusion equations because the mass flow "in" and the mass flow "out" is dependent on the gradient of ehh M. – In my mind. So if this is the level M times segment M, and this is level M at M1 and M of M – 1, then the mass flow from here to there will be given as something like, yeah, D-M D-Z. So if this is somehow the mass flow, then plug it in to there will give a second derivative."*

Interestingly the plates that during the former meeting were introduced as *objects* that provided the conceptual model construction with reference to the machine in the factory were now back as the outset for this discussion. The plates were thus maintained as a material reference from the previous meeting to this meeting, though they were now re-presented differently in the dialogue and in the drawings on the black boards. In the previous meeting the modellers assessed the plates´ potential functions regarding heat conduction and active propulsion of material through the drier. At the previous meeting, the plates were defined as entities with shovels that by rotating actively propelled material through the drier and with surfaces that conducted heat from superheated steam to the product.

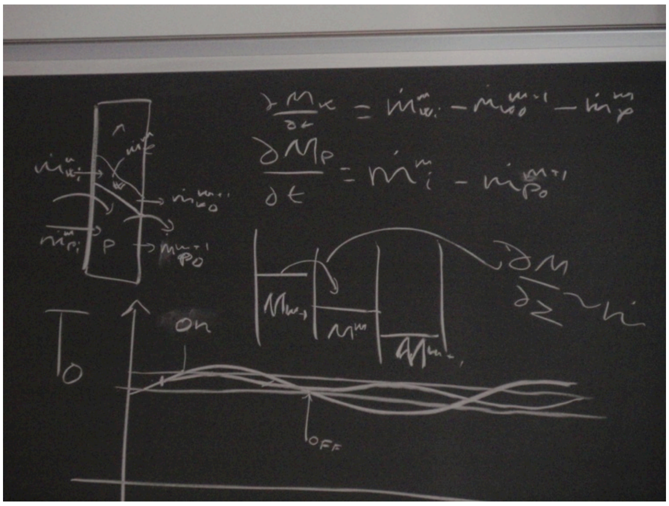


Figure 6.11: Black board illustration from the meeting representing the drier machine as discrete sections of masses. The representation is used to determine mass movement inside the drier as flows between the sections divided by the plates inside the drier. Picture taken by Author, fall 2011.

At this later meeting the modellers instead re-presented the plates as spatial dividers in the drier model on the black board. Figure 6.11 shows the modellers new interpretation of the drier. It can be seen that the “plates” that earlier were considered for their physical attributes as objects had now been reduced to vertical lines with the defined function of dividing the interior of the drier into discrete volumes with discrete masses.

The representation on the black board still portrays the plates as *objects* that condition the movement of the masses inside the drier. But now, the plates are used to assess the transportation of mass by separating the inside of the drier instead of accounting for the active propulsion. This interpretation of the plates´ *function* provided for a different translation of the phenomenon into a mathematical function.

Where explanations as ends are intended to offer explanatory power over a variety of elements, the plates as – *object* – or mere elements to be explained were here mobilized into different rationales for different explanatory agendas. One explanatory agenda was to take as outset the discretely separated masses and define the mechanism as diffusion, which mathematically translated into the effect of looking at the transportation – *function* – as a second derivative. The other agenda defined the transportation function as a flow, which instead translated into a mathematical interpretation of looking at the first derivative.

TRANSLATION: **OBJECT** → EXPLANATION 1: **DIFFUSION**
2. DERIVATIVE THEOREM

//ALTERNATIVE// → EXPLANATION 2: **FLOW FUNCTION**
1. DERIVATIVE THEOREM

The other modeller*: "Yeah but I don´t. I mean as soon as you feed something from one place and you take something out another place the transport will happen just by continuity and then by of course you have the energy exchange also, but as soon as you feed something then you will immediately have a transport."*

Another modeller: *" It is not necessarily diffusion. Put something in at the boundary that has to propagate through the system."*

The modeller at the black board*: "But you gonna drive it…"*

A modeller*: "Yeah but there must be 'that´s the M in' initiate all in the beginning that's the driving through. What comes in to the drier -I guess is the driving terms?"*

The debate continued on the controversy of with which kind of *function* with which the modellers believed to best able to explain the transportation of mass inside the drier. Was mass moving through the drier as a flow or as a diffusion function? The modellers agreed that mass moved in a certain direction, and that something must "drive" the transportation. But the modellers still did not agree on the mathematical interpretation of this movement and thus the mathematical *function* they believed could explain this moving *behaviour* of product through the drier.

At a point the modeller at the black board busted out:
"This is not fluid. I just realised, […] at some point that this is not fluid… "

Figure 6.12: One of the pictures that I showed the modellers during the meeting. Picture taken by Author, fall 2011.

At this point in the meeting I found some of the photographs that I had taken of the drier machine during my visits to the factory, to show the modellers the inside of a drier in operation. One of these photographs is shown in Figure 6.12. A modeller asked whether the metal parts seen between the meat content in the picture were the plates. The modeller at the black board came to our table and responded to my pictures:

”It doesn´t look like my view of things; that you have a lot in one end and not so much in the other end. There must be a distribution… “

The visual reference to the drier machine and it´s observed distribution of the product during operation; the – *behaviour* – of product, moved the discussion towards the flow distribution explanation.

One of the modellers: *“ I think if we have a volume, if we always keep control of the mass in a certain section and we know the volume of the section... So this is the way to calculate “online” what are the heights in each chamber and how it propagates”*

The modeller approached the black board and started to mathematically express what he was thinking and talking about:

“Then we have here …. And now… …So this tell us that… So the F over F… will be … So now we have. So this R-filling is...”

The other modeller: *” assuming that… “*

Modeller at the black board*: ” yes assuming… “*

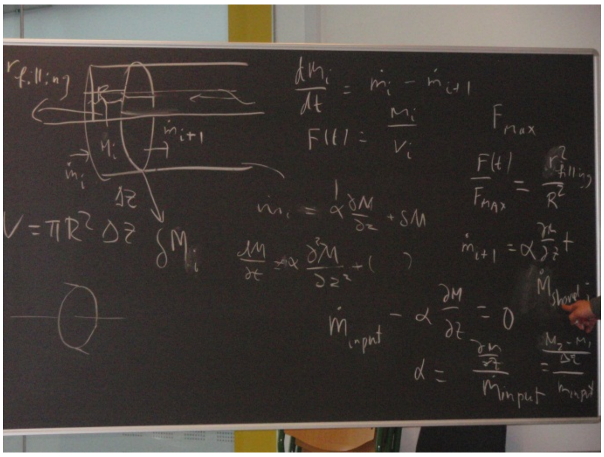


Figure 6.13: Another black board at the meeting being filled with mathematics. Picture by Author, fall 2011.

The modeller before arguing for the diffusion explanation entered: *” you could write this as just…” (Followed by an extended mathematical expression …)*

The photographs of the actual drier under operation served in this way the modellers´ work in translating the drier machine into mathematics. The new visual impression of the distribution – *behaviour* – of the product inside the drier provided insight to what kind of – *function* – that the modellers were to “simulate” in their model. The *function* being defined by the modellers to account for the *behaviour* of mass inside the drier, enabled them to translated physics into mathematics they could further manipulate.

What the modellers produced on the black board to account for the mass transport as a physical phenomenon, with reference to the drier machine at the factory, was at this point in the modellers´ work inseparable from the theorem used to describe that class of phenomenon in mathematics. When the modellers spoke of two kinds of transport *functions*, they referred simultaneously to the mathematics through which the physics was understood as to the physics that was belied to account for the detectable. When the modellers accounted for mass transportation as a diffusion-phenomenon they tied the mass transportation to a second derivative mathematical expression. When on the other hand a flow distribution was used to account for the mass transportation phenomenon, it was tied to a first derivative mathematical expression.

Partly because of the photograph I showed, the modellers believed that the largest amount of evidence, supported a flow distribution and thus a first derivative mathematical flow function. The modellers thereby collectively chose this to be the physical and mathematical explanatory agenda they deemed best suitable to answer for the known behaviour of the product moving through the drier machine.

TRANSLATION: (detectable) **BEHAVIOUR → 1. DERIVATIVE THEOREM**

Gathering Explanatory Allies

Aligning the model´s structure to a greater collection of information can be seen as an explanatory agenda that the modellers used to define a better answer for how the driers' transport-phenomenon functioned. Making the model an explanation for a more comprehensive collection of information can in this view be seen as organising the model towards becoming a stronger explanation by attempting to provide answers to a greater collection of elements to be explained. In this regard the mathematical modelling we have observed resonates with Latour´s notion of a Centre of Calculation, Latour (1987). The model was understood to produce a more powerful interpretation, the stronger it as centre were connected to the phenomena it was to explain. That was through incorporating more information at this modelling stage.

After a while of writing mathematical expressions on the black board the modeller said: *" So I think that we get the effect by this."*

Another modeller:" yeah-yeah, I think we have the effect in this model, but we would like to… ...find the value of alpha S..."

The modellers reached a point where they agreed that they "captured the effect" through their mathematical expressions. In other words, the modellers recognised that they had achieved to adequately "simulate" the how they understood the – *behaviour* – of the product moving through the plate drier by accounting for that movement as an "effect" of their mathematical function. The modellers thereby came to understand the mathematical function as an explanation that accounted for the primary cause behind how material moved through the drier machine. The mathematical expression can in this way be seen to have moved one step closer to become believed as an explanation for a specific type of – *behaviour* – among certain *objects* of the drier machine.

TRANSLATION: (detectable) **BEHAVIOUR → FUNCTION**
→ MATHEMATICAL EXPRESSION

Testing by comparing:
DETECTABLE BEHAVIOUR ← (simulated) **MATHEMATICAL BEHAVIOUR**

One of the modellers: "*So that's the question of what kind of process it really is? -Is it "grinding" or is it?"*

Another modeller: "*Yeah, because it depends a lot on the substance.*"

A third modeller: "*Like you say* [addressed to me] *and also what* [the coordinator] *says, is that in the first one* [the drier 1] *…have a lot of grinds. And in the first one the stuff that comes in is very wet because […] The first one is getting a lot of fluid."*

The modellers related their new mathematical recognition of the product´s moving behaviour through the plate drier to the empirically known behaviour of the physical machine at the factory. The modellers used empirical inputs for a kind of ad-hoc validation activity to confirm their new expression of the phenomenon through what had been recorded of that phenomenon. If the modellers´ mathematical explanation could capture the kind of behaviour that the machine had been reported to produce, the model can be understood to enrol that reported behaviour as an ally supporting the model to be a more believable and thus a stronger explanation.

In reference to Latour´s definition of an explanation where the mathematical model can be seen as belonging to the list of elements with which to explain as many elements on the list of things to be explained, the model gained more explanatory power as more information was included to what it could account for.

Expanding the Model by Combining Theorems

What at the stage of the second modelling meeting had been added to the model of the drier was another theorem that had been re-drawn and modelled to fit the modeller´s recognition of the drier´s transportation function. The outset for the second modelling meeting was a mathematical conception of the drier as a heating device. In that perspective the drier was understood as a machination that exchanged heat from a source to a recipient. The source being super heated steam and the recipient being the product that was subject to be dried. How that product was supplied to, transported through, and extracted from the drier were at the outset of the meeting not yet within the explanatory reach of the model.

Though the heat conduction was identified, as the primary function of the drier, heat conduction alone could not adequately account for how the drier worked. The recent advancement at the factory including the inlet and outlet -control experiments on the plate driers had increased the interest in better understanding the drier´s internal transportation mechanism. The second modelling meeting on the drier can thus be understood to be an activity with the outlook of expanding the explanatory reach of the drier model. The modellers did this by focussing on representing an additional function of the phenomenon. In this case the internal transportation function.

To summarise how the modellers produced a mathematical re-presentation of the transportation function, we have to go back to the outset of the modelling activity. In the second meeting the modellers used the same objects as they introduced in the first meeting. The plates still served as the central physical objects that providing the foundational material reference connecting the drier model to the drier machine. But in the second meeting the plates were means for a different interpretative agenda connecting different properties of the plates to other functions. By focussing on the plates´ spatial dividing properties in the drier, the modellers performed an interpretation of the mass distribution in the drier that enabled the modellers to define of how these discrete masses moved. Understanding this mass movement as either diffusion or flow connected the transportation function to different theorems according to which class of phenomenon the moving behaviour of the mass was understood to be.

The knowledge process performed by the modellers can thus be recognised as a cascade of translations connecting at one end the information about the phenomenon with a purified theorem describing an idealised and generalised physical phenomenon at the other end. In the first modelling meeting knowledge of the drier machines was connected with a theorem describing heat transfer. In the second meeting knowledge of the drier machine was instead connected with a theorem describing flow distribution.

The modelling activities can therefore be understood to perform the same material entities into different mathematically expressed phenomena. Although the modellers took the same objects as outset they translated these objects into functions as different as mass flow and heat transfer. An interesting performative aspect of the modellers' practice was thereby how they mathematically re-presented plural realities based on the same information about the same physical machine.

Translating Generalised Theorems Onto the Particular

Another perspective, through which the modelling practice can be understood, is to look at how the modellers applied theorems in their model construction. The way the modellers made theorems relate to the objects connecting their model to the machine. Where the modellers can be understood to exchange weight for mobility when they translated the drier machine into mathematics, the process through which theorems were made applicable to the specific implementation in their mathematical model followed a significantly different path.

A theorem in it´s pure form can be understood as a purified mathematically formulated abstraction of a specific class of phenomena. This essentially means that a pure theorem only accounts for phenomena in ways that are characteristic for how that class of phenomena is defined. In the "real world", machines such as the plate drier, work in ways that are far from what can be described through purified theorems. Theorems can on the other hand be useful to identify and describe what characteristic idealised features that are believed to account for a machine's operation. In this sense the modellers could be seen to apply theorems as ways of knowing what characteristic features of the machine they were to looking for in terms of translating their knowledge of the machine into a system that was mathematically manageable.

Another dimension of the how theorems were applied in the modellers´ practice was the way the theorems were mathematically translated to integrate with the particularity of what the model was intended to describe. Here the purified mathematical form of a theorem, that on one hand makes it mobile, generalizable, and relevant for a particular class of phenomena, was also what made the theorem distant from the particular phenomenon that the model was intended to explain.

The modellers therefore had to translate the theorems at the black boards in order to derive mathematical expressions that more adequately fitted the particular parameterisation of the model. The result of translating a theorem was a parameterisation specifically relevant to the model implementation and therefore not anymore of general relevance to that class of phenomena. What the modellers did when they parameterised the theorems into mathematical functions was thereby to exchange weight for mobility.

This mode of exchange produced the exact opposite direction of translation to that through which the factory was translated into information and made accessible for the modellers. The mode of exchange for translating theorems into parameterisations in the model was in this perspective also opposite in direction to the mode of translation typically associated with scientific practice as exemplified by Latour (1999) with Circulating Reference.

In this interpretation the modelling process can be seen to re-present the modellers' practice as two simultaneously occurring modes of translation. One mode was about exchanging weight for mobility, in order to produce information that re-presented the factory in the modelling meetings. The other mode was to mathematical rewriting theorems and exchanging mobility for weight, in order to particularise theorems so that they applied to the model´s specific parameterisation.

TRANSLATIONS: **FACTORY → INFORMATION**

INFORMATION → OBJECTS AND BEHAVIOUR

OBJECTS AND BEHAVIOUR → FUNCTIONS

FUNCTION → MATHEMATICAL MODEL ← THEOREMS

In terms of the translational orientations, modelling can be understood as a practice that combines purification in one hand with the opposite of purification on the other hand. Producing reference that connects the material drier machine at the factory with generalized mathematical theorems is a key characteristic for understanding the practice of the modellers. What the modellers end up with must therefore be recognised to be both particular and general, though not as particular as the drier machine itself, nor as general as the theorem. Instead the mathematical model makes more sense to be seen as a particular mediation between what is known of the particular phenomenon and what is known in general about different classes of phenomena.

A distinctive feature of mathematical models is often described in terms of how models enable modellers and model-users to draw together empirical and theoretical inputs in order to produce new recognitions. In this regard we have seen how the modellers in the regulation project applied several theoretical inputs into their model´s mathematical structure. We can see that the modellers were able to perform this kind of manipulation because the theoretical inputs they used were accessible as mathematical expressions –such as the theorems we witnessed the modellers to apply. An interesting recognition from this is that the modelling could be seen to not only combine data with theory (Sismondo, 1999; Winsberg 1999), but also to combine multitudes of different theorems. This seemingly small twist is central in order to understand how the modellers sought to transcend the explanatory reach of the single theorems.

The representative mathematical modelling in the regulation project can thereby be understood as a knowledge practice that simultaneously experimented with connecting data and multiple theories. A significant characteristic of the mathematical modelling was thereby its ability to not just draw together data and theory, but also to reach outside the re-presentational reality of single theories, by combining several theoretical perspectives. This unique feature of the modelling can be seen as key to how it approached a greater diversity of functions through which it sought to relate to the event of interest.

Modelling as a Knowledge Practice and it´s Epistemological Consequences

In Science and Technology Studies and within philosophy of science, modelling has been a heavily discussed subject for metaphysical classification, (see for example: Winsberg, 1999; Sismondo, 1999; Johnson, 2006). These debates have been polarised by two fundamental positions arguing for modelling to either categorically belong to theorising or experimentation. From these oppositions other positions have nuanced the discussion by proposing modelling to belong to a category in the middle of theorising and experimentation. Others have even argued that modelling belongs to a category entirely of its own and thus a third paradigm to the classical experimentation and theorising.

One of the main reasons for discussing the metaphysical stance of modelling is to qualify the epistemological consequences of the specific ways in which modelling produce knowledge and how modelling results should be perceived and applied (Winsberg, 1999) A classification of modelling in terms of theorising or experimentation would relate modelling to these knowledge traditions and their respective epistemological heritage. Regarding modelling as something entirely different that belongs to an epistemological class of it´s own, would call for an entirely new epistemology –one that is specific to modelling, and has therefore not yet been defined. The consequence of which, is that we yet have to find out how to understand and be critical towards knowledge produced through modelling. What we have witnessed by studying the regulation project's modelling is a practice that operated through a specific combination of the reductionist approach of experimentation and the deductionist approach of theory articulation. The way we can understand the modellers' knowledge practice is that they manipulated both re-presentations of their target system and re-presentations of theories in order to construct what they considered adequate alignments. These alignments of both theoretical- and empirical inputs can be seen what they used built the structure of their representative models.

What we more exactly can learn from our study of this special case of representational modelling will be further discussed in Chapter Nine. In order to set the stage for a more comprehensible discussion on the regulation project and is special use of representative modelling, we need also to study how the project enabled models to return and integrate into operational industrial environments. The next chapter will therefore illustrate a special case of how the regulation project brought back and integrated regulation models in a production environment.

Chapter Seven

From Mathematical Model onto Operational Implementation

The reality of how a mathematical model is made wild

A mathematical model disconnected from the surrounding world has very little to offer besides being an abstract description of parametrical relations. Mathematical models can be understood to offer a perfect but abstract reality where the mathematical laws are undeniable and determining truths. But if a model lacks reference to the rest of the world, it remains a mere description of relations between numerical or analytical variables in an abstract and detached mathematical reality. A model becomes effective only when it relates to the surrounding environment. It is through creation and maintenance of references that models can do what according to philosophers of science is to connect data with theory (Sismondo, 1999). In terms of Latour´s (1988) definition of an explanation, the explanatory power of a mathematical model depends on how the model as an explanation is connected to what it explains. In the previous chapter (Chapter Six), we explored how the mathematical modellers in the regulation project established a mathematical model as an explanation. In this chapter we will explore how a mathematical explanation is made effective by becoming operationally connected to its surrounding environment.

The purpose of this chapter is to follow how the practitioners in the regulation project connected a mathematical model to a new environment in an industrial installation. Where the previous chapter opened the lid on the “black box” of how production machines were translated into mathematical re-presentations, this chapter will instead describe the reverse process of how a mathematical re-presentation is brought “back” to affect the surrounding world. The practice we study in this chapter concerns the implementation and testing of an adaptive regulation model. An adaptive regulator is a different type of mathematical model than the model we studied the construction of in the previous chapter. Where the model in the previous chapter became a re-presentation *of* a target machine, the regulation models in this chapter was instead intended *for* operationalization onto a target machine. While the existing literature on simulation models has primarily concerned representative models in scientific contexts, this chapter introduces both a new societal application for modelling and a new type of mathematical model. The regulation model which implementation we are to study through this chapter was introduced to the production facility in the shape of computer code and carried in the hardware of a PLC (Programmable Logic Controller). The environment in which the regulator was to be integrated was a decanter machine that handled a specific part of the cleaning process in a wastewater facility near the small town of Hedensted. The implementation and testing was conduction by the regulation project's participants from CORE and Alfa Laval. The specific relation to the rest of the regulation project was that the experiences that were produced through this implementation and testing could be utilised on other decanter machines –such as those at the Factory near Løsning. Additionally, because the procedure through which the implementation and testing was conduction was similar to the way that regulation models were implemented at the factory, this chapter can be considered indicative of the general implementation method that was deployed in the regulation project. The reason for choosing this particular testing site was based on the ability to study the full extend of the implementation and testing procedure. It therefore made a good case study for understanding the specific type of implementation practice that was deployed throughout the rest of the regulation project.

The numerous field expeditions that this corner of my ethnography is based on were conducted in the period from September to December 2011. Through this field study I wish to further qualify how we understand what a simulation model can be, by turning my empirical lens towards what a model can be made to accomplish through its different material states during its implementation. Philosophers of science have predominately been treating models as abstractions through a representationalist account and often from a comfortable distance to the environment in question. While there is a lot to be said about how we can understand models' usefulness in a non-representationalist view (Knuuttila & Voutilainen, 2003), or as a special breed of scientific re-presentations, this chapter serves to illustrate a radically different setup than what can be designated to the typical conception of a model that re-presents certain features of a target system. In this chapter we are instead to explore how a model becomes an operational part of its target system. The case thereby offers unique insight to a specific type of model-based technology that challenges the conventional notion of models as re-presentational epistemic entities, by instead focussing on how a model is made operational.

In this description I will move the perspective on modelling, from abstractions to actions. The actions that I describe are practical doings of creating reference between the model and the model's target system. The intention of the practice, that I have participated in, was to enable the model to act upon its target system. The intention was in other words, to regulate the operational steering of the decanter machine. My descriptive approach to is to focus on how the mathematical model was translated into a regulation solution by paying close attention to how reference between model and its indented environment was produced. The notion of reference in this context is to be understood as operational communication between the given material states of the model and their working environments. This implies compatibility between both the hardware and the software of the different model states and their operational environments.

Actions are in this description defined as the practical steps needed to create a reference between the model and the object that the model has to act upon. If mathematical models can be understood as immutable mobiles (Latour 1986), my interest is to address how immutability and mobility of the model is exploited. Comprehending how the model was designed to address specific needs is also an important requirement for understanding the particular way the model was enabled to become a useful solution to a practical problem. What this chapter will focus on is what others may deem as incremental or insignificant challenges in making a mathematical model operational. We will thus look at how the model was enabled to provide a glimpse of the promising improvement that its inventors trusted it would ultimately generate when permanently applied to key process machinery.

Translational Perspective on Operational Model Implementation

In the former chapters it was described how the wild nature of the factory's production was tamed and transformed into data and information that was useful for representative mathematical modelling. Further we witnessed how this still very savage raw data and information was translated into a mathematical model by aligning knowledge of the machine with generalised knowledge about the world. This process of taming the wild in order to make it compatible with generalised theoretical knowledge, showed a path of subtraction and purification that was in overall agreement with Latour´s description of scientific practices by "packing the world into words" (Latour 1999). In the case of the representative mathematical modelling, the world was packed into mathematics in order to make it subject to analytical purposes. According to Latour´s field science example, the consequence of making the intermediate outputs of a knowledge production able to travel is a reduction of complexity and materiality, in order to purify and amplify the *meaning*. Latour exemplifies this consequence by the mechanism of translating matter into form, where weight is lost and mobility is gained at each step in the scientific process.

The process that we are exploring in this chapter is of a very different kind to that of the field science that Latour studied in Boa Vista. Contrary to the scientific practices deployed in the jungle of Boa Vista, the project that this ethnographical chapter covers only a small part of, consists both of, wrapping the production into mathematics, and then turning the mathematics back into the production.

The specific interest in this chapter is therefore to account for how the output of a modelling process is brought back to affect the production.

Within the field of Science and Technology Studies, it has been argued for more than thirty years that due to science being a part of society and vice versa, the same analytical approaches can be applied to both contexts. The transition of a local and practical interest into a natural scientific project, in which it is defined and translated into a knowledge output that is than translated "back" into the local and practical setting as a solution, has not previously been described through a detailed analysis that is coherent and compatible at all stages of the process. The regulation project can in this perspective be seen as a case where society has been described scientifically, and how the scientific descriptions were brought back to influence society. In this chapter we will see how this is done through the implementation of new regulation technology in an industrial setup.

The ontological and epistemological premise for producing a descriptive analysis that transcends and connects the domain of science and that of the technological implementation therefore has to first of all, address subject matter that is compatible across all the practices that are under study. Second of all, the different practices have to be treated through a compatible analytical framework. I will therefore extend the translation analysis that I applied on the model-construction practice in the preceding chapter, to the model-implementation in this chapter. We will still look for translations, though of a different kind and with a different outset – namely that of implementation and integration in a very different material setup. I will continue to pay close attention to how weight and mobility are exchanged, and for what purposes this exchange is done, in order to illuminate the challenges bound to bringing back something scientifically tamed into the wild order of an industrial production facility.

Bringing the Tamed Back to the Wild

In order to accomplish this, I will introduce the analogy of ethology, which is a special category of zoology that draws on a well-known, however very complicated practice, to explain the generally little understood process, as well as the involved craftsmanship, when implementing scientifically generated knowledge onto an industrial setup. The issue that scientists and practitioners, within the field of ethology, have been addressing ever since humans became interested in the wild as something worth exploration in natural settings, rather than exploitation in civilized settings, is the great challenge in helping wild animals without undermining their fundamental survival abilities. Taming and making use of wild animals for operational purposes like watch dogs, live-stock, or horses for transportation, were invented and developed long before the interest of re-introducing what had been tamed to the wild. From purely haven been domesticated for human purposes, the interest in reversing the process and making animals wild, represented a very different end. What soon became an important experience for ethologists was that it was notoriously more difficult for domesticated animals to return and survive in the wild, than taking an animal out of the wild and tame the animal for civil purposes.

What I wish to address through this analogy is that act of applying scientifically generated knowledge onto complex societal surroundings, like the ethologists, face a very different type of challenge than those of the “pure sciences”. Contrary to the pure sciences, applied sciences do not only have to tame the wild, but also to enable it to return to the wild and survive.

The wild is in this metaphor the complex and little controllable nature of the practices and the processes as practitioners and their machinery conduct them. The jungle with its wild life, vegetation, and geographical and climatic conditions is therefore exchanged with another confusing complexity consisting of a plurality of practitioners, machinery, legal, economical, and physical laws.

The schism I seek to unfold is that of the very different nature of producing descriptive knowledge based on wild systems, like representational modelling, and the nature of reintroducing such descriptions back to the wild. What I attempt to make visible through getting in touch with the realities of reintroducing a tamed model to the wild, is first of all how difficult it actually is, and second of all how different these difficulties are from those we have experienced by studying cascades of scientific purifications taming the wild in the first place (Latour & Woolgar, 1979; Latour, 1999).

In relation to how Latour (1999) described the expedition to Boa Vista, I want to further unravel the process of applying what has been developed already, by bringing back the purified and general to the particular, material, and complex settings, where it must proof its worth. What Latour described as applying different maps “covering” the same area to superimpose inscriptions for producing an indication of an exact location, I aim to follow this process of moving from the general, immutable, and mobile recognition “back” to the particular and material setting on the floor of this wastewater facility.

In his descriptions, Latour renders a slight implication of what I want to further untangle, as he provides some hints of how the general and mobile maps are translated to be applicable to the specific needs of the scientists, in the otherwise confusing and unmanageable jungle of Boa Vista. What Latour imply by: *“the beautiful yellow, orange, and green colors on the map do not always correspond to the pedological data.”(Latour 1999. P. 28)* is that correspondence between map (the compatible, standardized, mobile description of relative universality) is not given on beforehand, and depends on the ability of those who seek the correspondence, to create it in the particular situation.

The focus I am trying to construct is that the translation from the general to the particular is neither straightforward nor given, as the terms of the particular situation will call for adequate translations unique for that particular situation. This perspective is vaguely illustrated by the way that Latour describes how the scientist who he follows into the jungle works with their maps: *"(Both of Armand´s hands and Edileusa´s right hand must continually smooth out the corners of the map, otherwise the comparison would be lost and the feature they are trying to find would not appear)"(Latour 1999, p. 29)*. Reference is constructed on site to a degree uniquely adequate to the specific situation.

The Habitat

In zoology wild species are understood to inhabit unique habitats that are defined by geographical conditions and the specific purposes, which are filled by particular species; what they consume and what they are consumed by. In the same way the production plant, which is the basis of this ethnographic description, also makes up what could be perceived as habitats for the different sub-processes that it is inhabited by, and what makes it run as a part of a greater "eco-system" with external suppliers and customers for what is produced. To appreciate the challenges experienced when reintroducing something tamed into the wilderness, the specific purpose and role in the larger eco-system needs to be clarified, as these are the conditions under which it needs to survive. The following description will therefore unfold the basics of the habitat, in which the tame model is to be set free, to make it possible to understand its particular working conditions in this particular site. In other words, the wild conditions under which the model will need to survive, be operational, and not the least useful.

To run a regulation model it needs to be implemented and integrated into operational settings. What we are to explore in this chapter, is a particular installation that handled wastewater in Hedensted. The central machine that facilitated the process that we are interested in, was a decanter manufactured by Alfa Laval, for which I followed the development of many of its implemented innovations (Juhl & Rosenqvist, 2009).

The colleagues that I accompanyed this morning at the expedition to this remote site near Hedensted, were the organiser of the regulation project the head of concept development from the decanter manufacturer. To help us engage with the decanter at the technical level, the decanter installation-expert also from the manufacturer, picked us up at the nearest train station. The specific purpose of this expedition was to make a new PLC regulator able to externally connect and run a newly implemented wastewater decanter. In order to be able to engage with the regulator side of the implementation, the regulation consultancy's PLC expert met us at the site. He had done the programming of the adaptive regulation models onto PLC that should enable them to be installed on a range of process machinery.

The regulation consultancy had already tried to test the new PLC several times before on this and other installations, but complications regarding the communication between the existing steering of the decanter and the PLC, had obstructed the testing. The connection of a PLC to a machine and its operational steering is no trivial task. The point at which I was introduced to the project's implementation regulators was not their first attempt at this particular site. The heavy support from both the PLC expert, and the decanter experts to this seemingly incremental mission, was a sign of the highly specialised skills that were needed for making this experimental setup, functional. In the following I will address the specific conditions under which a model was enabled to run this industrial machine process; in this case a decantation process that which purpose was to remove solids from wastewater.

Entering the Wastewater Facility

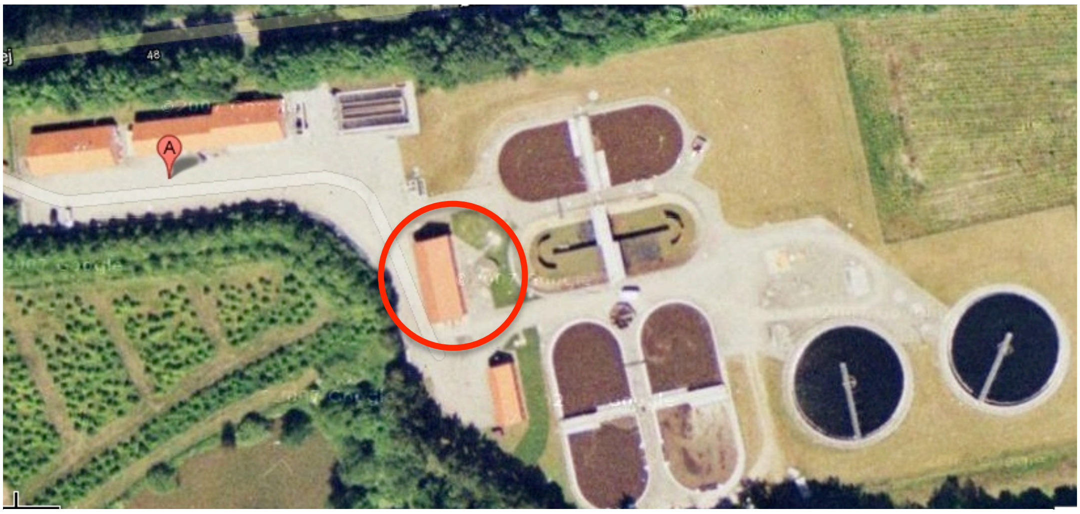


Figure 7.1: Hedensted wastewater facility. Picture taken from Google Earth 2012.

At our arrival, the decanter expert showed us the decanter installation and how it operated. Optimisation of this decanter's operation related to the specific function it had as part of the entire production chain at the wastewater facility. In order to understand the function of the decanter at the wastewater facility, I will therefore introduce the basic production processes that were conducted at the facility. The decanter installation was housed in its own small building (see the shed with the red roof in the middle of figure 7.1). When in operation, the decanter was fed by wastewater that it transformed into cleaner wastewater and sludge. Sludge was formed as a concentrate of the solids that the decanter separated from the inlet wastewater. This step was driven by electrical power, and in addition a specific polymer was added to the inlet wastewater in order to improve the sedimentation process that produced the separation. The wastewater that was supplied to the decanter was taken from either of several outside tanks. Figure 7.2 shows the water hose through which water was pumped from the water tank right behind where the picture was taken from and into the decanter shed. In figure 7.3 we see the decanter installation that receives the wastewater. Before arriving at the decanter the wastewater has been through an extensive cleaning process.

Figure 7.2: Hose supplying wastewater to the decanter shed. Picture by Author, fall 2011

Figure 7.3: The decanter seen from the end that receives the wastewater. Behind us we have the control installations. Picture by Author, fall 2011.

The “raw” wastewater was collected through a discharging system that connected 1200 nearby households and eight towns among which was Hedensted and Løsning where the factory we visited in chapter five was located. Initially at its arrival, the wastewater was received through mechanical fine grids that removed particles and objects of sizes greater than 3mm in diameter. These objects –typically rags, plastics items, and cotton buds were automatically transported to a washing/pressing zone at the facility and ended up in a container that goes to an incineration plant.

The sand- and fat content in the raw wastewater was thereafter removed. The sand was reused as fill and the fat went to the biogas facility. After this, the wastewater was supplied to the biological and chemical process tanks. Here the biological compound ammoniac was removed by supplying active sludge and oxygen that transformed the ammoniac into nitrogen. By cutting off the air supply, the nitrogen was released from the water and could thereby be dissipated into the atmosphere. When the biological material and nitrogen had been removed, the water was led to tanks where the active sludge could settle and deposit before being pumped back to the process tanks where it was reused.

Besides the organic compounds, the phosphor content in the wastewater also had to be removed. Supplying iron-sulphate and aluminium-sulphate to the process tanks produced chemical sludge that bound the phosphor. The chemical sludge could thereafter be removed from these tanks. After being exposed to the oxidization stair, the cleaned wastewater could be released to a nearby creek.

The specific task of the decanter at the wastewater facility was to separate and concentrate the excess sludge. The biological and chemical sludge that was not reused in the process tanks was stored and concentrated in dedicated tanks before it was pumped to the decanter. The decanter's task was to drain water from the sludge and thereby concentrate it from its initial content of 1 to 2 % to above 20% solids.

Figure 7.4: The decanter shed and the two sludge containers. Picture by Author, fall 2011.

In this chain of biological and chemical wastewater purification, the decanter served the important role to remove and concentrate excess sludge from the cleaning process. What entered the decanter shed was wastewater containing 1 to 2 % sludge and what left the shed were cleaner wastewater and concentrated sludge with less water content. The concentrated sludge that left the decanter shed was transported directly to the two blue containers that were located at the open end wall of the decanter shed (see figure 7.4). These containers could then be transported to the incineration plant. Because of the energy needed to the incineration, the wastewater facility was billed per ton sludge that had removed. This arrangement emphasised the importance of the decanter's process quality. The more water the decanter could remove from the sludge it delivered to the containers, the more it would save.

Getting to it…

The first thing the decanter specialist did, when we arrived, was to inspect the decanter machine. From previous experiences with trying to drive the decanter from an external PLC had entailed a variety of problems. The visual interface of the decanter steering was called the “two touch” interface after its intended ability to enable operators reaching any function with only touching the screen twice. The two-touch interface was placed on the cabin at the wall next to the decanter. It formed the primary connection between the operator and the decanter. As the decanter expert taped into the system, its the screen indicated a malfunctioning sensor that prohibited him from starting up the decanter. He therefore needed to inspect the decanter in order to locate the sensor that was detected as malfunctioning.

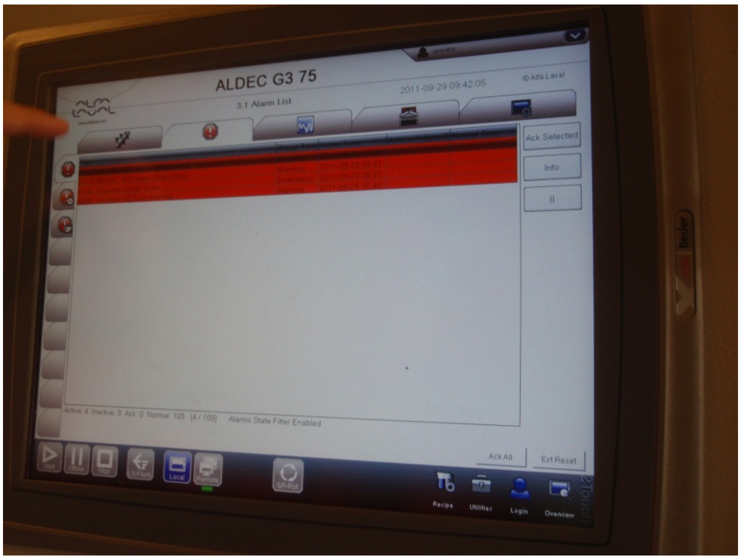


Figure 5: The two-touch interface showing the sensor error.

In Figure 7.5 we see the decanter steering’s two-touch interface. The sub menu signifies the detected sensor-error by marking the command lines in red. Like the maps of Boa Vista that was brought by Armand and Edileusa in Latours ethnography of circulating reference (Latour 1999), the preparatory work conducted by others before us, was present at the wastewater facility and conditioned the actions of my colleagues. In Boa Vista the maps were crucial for the crew to find and locate the part of the forest they wanted to cultivate for their field study. Here at the wastewater facility’s floor, the information architecture re-presented by the touch screen both helped our recognition of a potential problem, while it also prevented us from conducting the testing that we intended to do. While this screen provided us with a view over the wild nature of the facility’s materiality with all its machinery, vents, contacts, sensors, and not to mention the forces at play when the large decanter would start to digest wastewater, it also made these entities distant. Where were those sensors, and what was the problem exactly? Not to mention, what could we do about it in order to get on with the testing? Although this delay postponed the decanter testing, which was unfortunate for the testing, it was also fortunate for us, because it offered me a chance to get more “in touch” with the decanter’s sensory system.

In figure 7.6 the decanter expert inspects the power tubes on the decanter. These were special devices that directed the outlet of water from the high-pressure milieu inside the spinning body of the decanter's body. They were an improved version of the Power Plates described in (Juhl & Rosenqvist, 2009) and (Juhl & Gylling, 2011).

Figure 7.6: The decanter expert has opened the decanter to check its sensors and clean it. Picture by Author, fall 2011.

By steering the direction of the water backwards against the rotational velocity of the fast spinning bowl body, power tubes and power plates were intended to decrease the energy loss related to the pressure drop that occurred when water left the internal high-pressure conditions an entered the low-pressure outside conditions. If these power tubes were clotted with hardened sludge, it could affect the decanter's start-up and cause suboptimal processing conditions. It was therefore important to clean these tubes before start-up. (This is what we see that the decanter expert is doing figure 7.6). The decanter expert also scraped off sludge from the bowl body as the mass of the sludge could cause problematical vibrations when the decanter started to spin. Just between the hands of the decanter expert we can glimpse a small wire coming out from the machine. This is where the gearbox connects to the internal conveyor screw inside the decanter body. The wire was connected to a sensor that measured the torque on the axel between gearbox and conveyor screw. Behind the gearbox a similar sensor was placed that detected the torque on the axel between the motor and the gearbox. These torque sensors enabled the decanter's control system to detect abnormalities in the drive chain's torque distribution. Considering the driving forces at play when the decanter would be running, the torque alone was allowed to approach 8kNm. This equalled more than twice of what the most powerful road going trucks can produce. With those forces at work only a few cm´s behind us, it was reassuring to have an intelligent torque monitoring system.

I will later show how the outputs of this torque monitoring system are critical. Besides it's important safety features, this torque monitoring system was also responsible for the quality of the separation process. Additionally, the system's graphical interface produced a visualised reality that was central for how the separation process and its challenges were understood and approached through automated regulation. In the same vein as the field scientists in Boa Vista simultaneously pushed away the forest in order to bring it closer through lighter and more manageable re-presentations (Latour 1999, p. 30), I will later show how my colleagues at the wastewater facility also relied on re-presentations in order to assess the inner workings of the decanter. This technically refined, yet difficult-to-access sensory system, was key to connecting us with the inaccessible inner workings of the decanter. Although we would be standing right next to the spinning body of the decanter, what happened inside its body would be totally ungraspable unless the sensors and the graphical system re-presented lines on a plot through which we could relate to the machine's operation. But in order to get to this, we first need to look into how the mathematical regulation model had been brought to this particular site, and how it was operationalized onto the existing process equipment.

Codification of Model

While the decanter expert checked up on the decanter and made it ready for start-up, the PLC expert unpacked his gear and set it up inside the decanter shed. The key items he brought were a suitcase containing the regulator and a laptop along with various cables for connecting the regulator to the decanter steering. In order to grasp what the PLC expert had brought into this dirty factory floor, we need to go back in time and space and have a look at the initial stages of the modelling work and the necessary preparations making the present activities at Hedensted possible. The initial form of the mathematical model on which the present regulation model was based, had to be prepared so that it could connect to, and operate under, the same conditions as the decanter. The PLC expert therefore had to translate the mathematical model in order to make it work with appropriate machine codes. A translation that took as outset something formulated in the relative universal language of mathematics and turned it into a particular machine code language that was limited in application to specific types of operative systems. Through this translation general universality had thus been exchanged for specific applicability, by trading away mobility for weight (Latour, 1999). In order to comprehend the codification

Figure 7.7: PLC expert kneeling in front of the control cabin while setting up the equipment he just brought. Picture by Author, fall 2011.

preparations on the model that had been made prior to our field expedition to Hedensted, we need to know more about what the adaptive regulation model was and what it was intended to do during the testing.

The Adaptive Regulation Model

Compared to existing regulation models, the adaptive regulation model was explained to be a more "intelligent" model. Parts of its "intelligence" rested on its ability to use the historical development in data from the connected equipment in order to adapt its regulation. The performative end of this adapted regulation was intended to minimize an oscillation problem that was a common to typical Proportional-Integral-Derivative (PID) process regulation. The basic working principle in the adaptive regulator was that it could apply the historical development in the data to predict how the data would continue to develop and thereby adjust its regulation accordingly. Standard (PID) controllers typically regulated according to the difference between a current detected value and a set-value. A set-value in regulation terms is also often called "the set-point". It is the intended target value that the regulator is programmed to make the process equipment approach.

According to CORE, the major difference between a standard PID regulation and their adaptive regulator was that the progression of data from a running process could sometimes be above or below the set-value, and moving towards the set-value with a speed that a regulator should counter-adjust for. If the regulator does not counter adjust, the process will as a consequence "overshoot". This means that the regulator drives the machine past the set value into another situation, where machine's data-value also is off compared to the set value. This process problem is called "oscillation" because the regulator in its attempt to force the machine towards the set value instead cause the machine to oscillate around the set value. It is generally understood that PID regulator implementations are insufficient for detecting and preventing oscillation. The adaptive regulator had instead been specifically developed for detecting and adjusting for the data-values in a particular way was claimed to minimise overshooting and oscillation. The adaptive regulator was thus intended to improve process control, which would mean that it would be possible to have a process that operated closer to the intended set-value. While this claimed advantage should bring great benefits in terms of process stability and safety, it was also interesting because it promised the possibility for optimising set-values. Because the typical oscillations around a set value meant that the set value had to be chosen accordingly to prevent that the machine entered data values that was considered dangerous, a tighter control and less oscillation meant that the target value could be set higher without causing safety or stability issues. A promise of this freedom was for instance that the decanter could be run with a higher torque in order to remove more water from the sludge. This would mean savings on the incineration of sludge.

According to the implementer, who was the founder and director of the regulation consultancy company, their adaptive regulator was relevant for any industrial process equipment that had a process time, that was significantly larger than the response cycle of its regulation. In other words, the adaptive regulator was intended processes which reaction time to a regulator's input adjustments was much slower than the time it took its the controller to produce a new regulation input. The universal mathematical adaptive regulator expression therefore had numerous potential implementations. Yet the possible implementations would remain potential unless the mathematical model was translated from a universal expression, and onto the particularity of the specific settings in which it was to be implemented.

Linguistic Translation

For enabling the mathematical core expression to interact with existing process equipment, the PLC expert had supported the regulation company in (re) writing the model into computational code and program it onto PLCs. This linguistic translation process was the first step in the process of making the model more particular and better adapted for the "wild" environment of the wastewater facility. The choice of which PLC type to use, had also played a role –both for the choice of coding language that the PLC could process, and for the equipment that the PLC – containing the regulation model - could become connected to.

From having a developed mathematical model that had been under continuous improvements through various modifications since its inception, there was quite a leap in order to make it integrate with live settings. Though, immutable and mobile, the mathematical expression, which in this case was materialised as the adaptive regulation software on the PLC, was initially not materialised in a language that was designed for practical implementation purposes. Before having a neat suitcase to mobilize the regulator, the regulator needed to be reprogrammed in a PLC language. This entailed that the regulator, initially being a mathematical function, was translated into a computer code that could be transferred to the PLC. When downloaded to a PLC, the code was materialized in a form that was more practical in terms of interacting with modern PLC steered process equipment. These first initial translations that was carried out long before I became part of this regulation testing process was, in my terminology, of a *codification* nature. The re-codification of the model served the central need in making the mathematical function able to communicate with the necessary hardware. In this case a new PLC, which the regulation company aimed to use as their platform for implementing regulators in a greater variety of industrial process equipment i.e. that at the Løsning factory.

Model Distribution

The significance of the implementation process the I describe in this chapter was not limited to generating evidence for the merits of the adaptive model in the specific operational context of the wastewater facility. It was also about testing the implementation of a new and more broadly applicable PLC type. It was these experiences that tied this particular event at the decanter wastewater site to other potential process equipment i.e. the decanters, coagulators, and plate driers at the factory in Løsning. The regulation consultancy's aim was to deploy this new PLC as their future connection platform to a broader variety of industrial equipment. The ability of this PLC to be programmed with a regulation model and preserve it, carry it, and connect it to other equipment was also at stake in my colleagues' attempt to operationalize the regulation model.

In order to make the PLC that carried the regulation model, able to operationalize the model, it needed to be able to connect and integrate with other process equipment. In this case, it was the equipment at the decanter shed that was steering the decanter. On a basic level, the PLC carrying the regulator software had to be made able to connect with the PLCs that were built in to the existing process equipment. In this case the PLC controlling the decanter. In order to do this, the preparations of the PLC expert did not end at programming the PLC. They also included arranging a portable suitcase that could carry the PLC and the various interface modules it needed in order to become operational. It is these practical preparations that enabled the model to be brought to the test site and to be processed in accordance with incoming signals, and translated into a steering signal, which could be transmitted to the existing steering of the decanter.

Figure 7.8: The suitcase containing the Siemens PLC and interface-modules. Picture by Author, fall 2011.

What we witnessed when the model was brought to the wastewater facility was a translation that made the beforehand general and relative universal codified regulation model, gradually more materially particular and compatible with the present operational conditions at the site. Through the regulation model integration, we witnessed a process that resembled Latour´s (1999) terms of translating matter and form. However what we can understand the regulation attempt at the wastewater facility to do was not about translation matter into form. Instead it can better be comprehended as a process of out-folding form onto matter. The process, through which weight was added to a regulation model, in order to make model compatible with the particular material surroundings of the wastewater facility. Looking down into the suitcase that the PLC expert brought to the wastewater facility, the mathematical expression can certainly bee seen to have gained weight in this materialised state that was carried in form of the suitcase.

The PLC expert, who assisted by writing the software code version of the regulation model and program it onto the PLC hardware, had also arranged the handy suitcase to carry the PLC. In this suitcase the PLC was arranged together with various interface-modules as seen in Figure 7.8, and later in Figure 7.9. This translation was of a practical nature and built on the know how that the PLC expert had developed during the many years he had worked with the practicalities of connecting new computer code to existing industrial equipment. I will term these practical translations that were made to enable and ease connectivity to various equipment; *Distribution*.

Model Operationalization

After the decanter expert went through the decanter to check that the various parts were, as they ought to be, he used the two-touch interface to locate the sensor on the decanter that operative system claimed to be faulty. Unfortunately the system could not help locating the exact sensor on the decanter and the decanter expert was not able to delimitate which sensor to change. In order to find a way around this problem that prevented the decanter from starting up, the decanter expert phoned his headquarter to speak with a specialist in the two-touch interface system. The idea was to find a possible way to manoeuvre around the operative interface. The steering system would not allow the decanter to start up while the fault was there. By tapping in a dedicated specialist code to the two-touch system, the decanter expert was granted access to a deeper level of operational controls in the steering system. In its full scale the two-touch interface could provide 120 different pages each offering different operative parameters and functions regarding for instance the way the decanter was steered and safety settings.

The decanter expert then disabled the fault because it was judged to be of less importance, and that the testing could be conducted safely in spite of the warning. The operators at the wastewater facility could not enable all the 120 pages of operation. They were only supplied with a code that offering the much more restricted operator-access. According to the decanter expert, this was made as a safety feature in order to avoid that operators altered fundamental settings that could cause breakdowns or generate safety issues. In this way the decanter manufacturer could ensure that their product would live up to the promised specifications, and that a potential break downs or malfunctions of the machinery would not be caused by human errors leading back to the operators. In this case the safety feature also meant that the decanter expert had to acquire a dedicated specialist code to access a deeper level of the two-touch system that made the later testing possible.

One of the crucial features that the decanter expert had to adjust was the calibration of electrical signals connecting the external PLC to the decanter steering. The PLC expert assisted the decanter expert on this crucial task because the calibration required correspondence between the external PLC and the receiver in the decanter steering. The PLC expert told that choosing 4mA to 20 mA was a common choice in the industry. By setting the zero level to 4mA ensured that any leak or unwanted influence that dragged the current below 4mA would be detected. The adaptive regulation model, which was the basis of the regulator function in the PLC, operated in levels from 0 to 10. Zero regulation level was thereby calibrated to be equal to transmitting 4mA to the decanter steering. This enabled the internal decanter steering to disregard a false signal and to continue its operation if nothing was received from the PLC. This was a very comforting feature considering the forces at work just a meter behind where we stood.

These settings meant that the discrete current levels that was passed from the external PLC to the internal decanter steering were to carry the steering signal. The PLC expert explained that the PLC quantified the steering signal from 0 to 10 into 32´000 levels, which then corresponded to a certain current level between 4mA and 20mA. The only steering parameter concerning the decanter´s operation, that we were attentive to during this test, was the "differential speed". Differential speed meant the difference in rotational speed between the outer bowl body and the internal conveyor screw. The signal from the external PLC regulator would tell the decanter steering how much the conveyor screw should rotate slower than the bowl body. What this meant was that the differential speed of the conveyor screw in the decanter was controlled through the level of the current received from the PLC –only when it was within the 4mA to 20mA interval, which again corresponded to a quantified level between zero and 32´000.

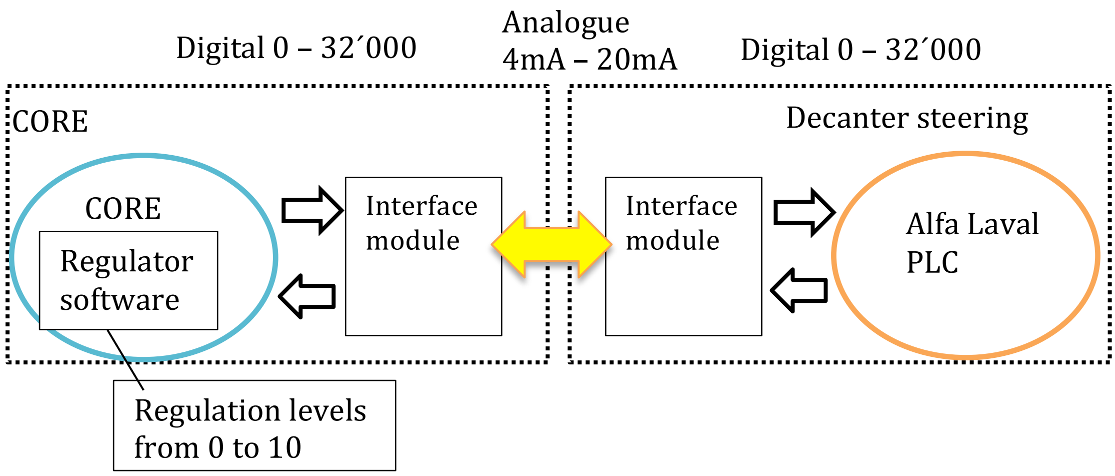


Figure 7.9: Simplified illustration of the basic working principles of how the CORE PLC is capable to communicate with the integrated decanter steering. Illustration by Author.

Data alignment was central to the work of the skilled experts and specialists at wastewater facility. As we know from Latour´s example of the cooperation between two scientific practices in the jungle of Boa Vista, acquiring a reference common for the two domains of work, to which data could be aligned, was crucial for achieving the goal of their field activities. Like in the forest of Boa Vista, the work of the two different specialist teams could have been conducted separately, if it were not for the novel task of superposing their domains. However in both Boas Vista and in Hedensted, the sole purpose of the activities of the two specialised groups, were to integrate and superimpose their work. Without both the soil digging pedologists and the plant-collecting botanist, the expansion/retreat controversy of the Boa Vista forest would not have been accessible. And without both the model implementing CORE specialists and the decanter operating Alfa Laval specialists, the technical controversy of making the adaptive regulation model able to act upon the decantation process, would also have been inaccessible.

Figure 7.10 shows two PLC experts trying to figure out why the PLC does not receive any signal from the decanter steering. In order to work, the PLC had to receive data from the decanter steering, while the process was running. The PLC was to receive data concerning the torque performed by the decanter's motor and the differential speed between the conveyor screw and the bowl body. Great attention was directed towards how the cables were connected. At the picture we can see one of the regulation experts pointing at a connection inside the cabinet as he and the other PLC expert went through the hardware connecting the CORE PLC with the decanter steering.

This industrial installation seems to take the heads and hands of four highly qualified specialists to get around. Two who were specialists in the domain of regulation and the PLC implementation that carried the regulation model. And two who were specialists in the decanter, its installation, adjustment and its operation. Between these two specialised professional domains; that of regulation technology and that of the machine-installation, a novel and very particular domain emerged. A domain that arose as a particular consequence of the practical reality that both made up the potential, and yet still was what prevented, the two groups of experts, to make the regulation operational. This novel domain was specific to the place and the situation and was constituted by the overlap between the regulation technology and the decanter installation that the two specialist groups were trying to establish. Integrating these two existing technological domains seemed to create a new and unknown one. This new, uncharted, and still non-operational overlap was what occupied the four specialists in their attempt to make the regulation model run the decanter.

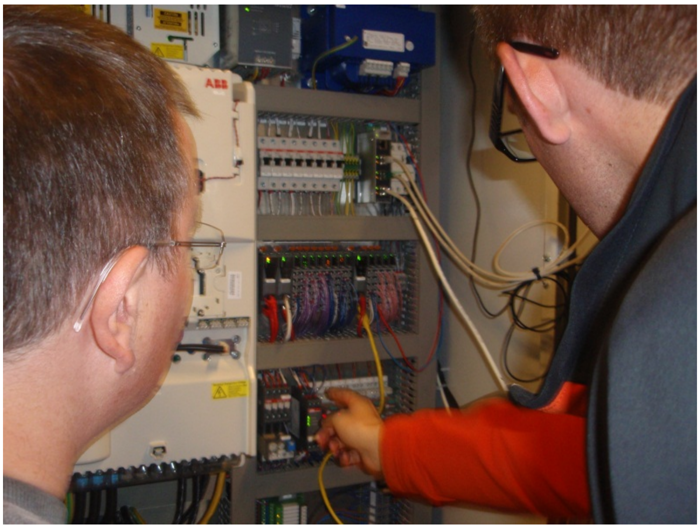


Figure 7.50: Regulation experts looking into the decanter´s control cabinet searching for the reason for why the connection isn´t working. Picture By Author, fall 2011

Knowledge at the site

Besides pointing at a physical object in the chain of machines and connections between the CORE PLC and the decanter steering, the finger of the regulation expert in figure 7.10 also points at a piece of the practical reality which at that point in time still kept the two specialist domains separated. Though the finger showed not to be indicative of the exact problem in this situation, it is indicative of the novel and explorative nature of the work that the four specialists were conducting at the site. Though they were not performing what would normally be considered a scientific breakthrough, they were struggling with the practicalities of realising techno-scientific advances. Making the intelligent and adaptive regulation technology re-presented in the regulator suitcase able to operationally integrate with the latest decantation advances re-presented by the third generation decanter and its two touch interface, was what was at stake at the dirty floor in the shed at the wastewater facility.

Making those two domains able to communicate and work together was not a given and demanded the four specialists from the two separated domains, in order to develop an adequate and practical solution at this specific place, in this specific time, and under those particular circumstances. The reality was that these practical doings were determinative for making the technology able to perform as it promised, but yet such incremental practices are practically never spoken of. Instead they mostly remain tacit know how for those who are present and involved. The experience produced through this activity would remain individual and specific to the particular circumstances in this situation, if they were not documented, extracted and analysed for the purpose of being disseminated as intellectual literature. Though the knowledge that went into making an adequate solution in this particular situation may be difficult to generalize and make generally applicable, the activities that produced that particular solution, seemed to be central for the outcome of the presented technology and the promises that had been made on its behalves. Making those promises come true seemed to be as much about creating practical solutions on the dirty floor and at the end of the index finger on the photograph.

Adequate, yet equally determining novelty in this situation appeared to be found in the most simple of forms. By going through the hardware and the software of the installation, one of the regulation experts found that it was a feature that had recently been implemented to the suitcase, that caused the chain to brake down. The feature was a set of switches that he had implemented due to a previous experience from conducting tests on another decanter steering. The function of the switch was to manually enable and disable the in- and outputs of the suitcase containing the PLC. This had proven to be an important feature for engaging or disengaging the regulator while a decanter was running. It was originally implemented as a safety feature to avoid making the CORE PLC prematurely take over the control of the decanter, but now it appeared to be the last obstacle that prevented the required connection. Flicking the right switch and joyfully bursting out: "aha, that´s it!" the PLC expert finally enabled the data from the decanter steering to enter the PLC.

I was later told at the annual Christmas lunch held by the regulation company that the extension of time alone that they could spend on the technicalities at each expedition to the wastewater facility was indicative of the success. The point was that they could only continue to work until they encountered challenges that exceeded what they were able to find a practical solution for on site. The crucial ability to continue to work and overcome the challenges that arose on site, was not a given. Their first visit to Hedensted lasted only about 20 minutes. At their arrival, they had been met by a problem that could not be solved on site. Though perhaps trivial in the face of great technical endeavours, they were confronted with an incompatible connection for which the interface and the cables they had brought rendered useless. This implies a strengthened emphasis on the importance of the preparatory work of the PLC expert in making the versatile suitcase. A suitcase containing a regulation model that could be brought in a form that enabled it to matter in the novel and likely unforeseen situation that would arise. The unpredictability of such testing can be seen as a consequence of superposing two otherwise separated technological domains.

Where I entered the process and where this empirical description took its departure, was at this operational stage where the preparations made in the previous codification- and distribution stages were to be translated into action, by integrating the regulation model into the particular setting of Hedensted. This implied making the actual connections between the regulator and the process equipment, and test how it managed to control that equipment. The model operationalization of the implementation process also implied making the process equipment ready for the testing. In the case of Hedensted this was exemplified by the work of the decanter expert. Though the importance of this practical element has not been thoroughly unfolded in the above description of the wastewater integration, it was essential for the whole test arrangement to produce a successful test. For the regulator testing to be operationalized successfully, we can see that all the particularity, materiality, locality, and know how had to mesh together in a new and unpredictable way. In contrast to reductionist scientific practice, this practice expanded its connections and reliance to the multiplicity at the test site. Instead of ridding a *meaning* from materiality, locality, and thus weight, my colleagues had on the contrary added materiality, locality and weight in order to realise the *operational* potential of the immutable and mobile regulation suitcase they brought.

Inscribing Model Operation

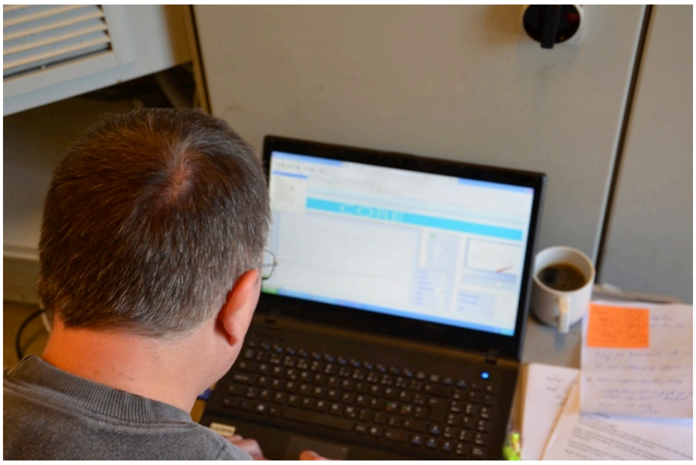


Figure 7.11: The PLC expert in front of his lap top monitoring the CORE model regulating the decanter. Picture by Author, fall 2011

At Figure 7.11, we see the PLC expert looking at the screen of his laptop. The screen functions as an on-site and on-line visual interface to the adaptive regulator inside the suitcase below the laptop. The interface showed the continual values of the measured motor torque and the differential speed. These data values were plotted as two-dimensional graphs by forming coloured lines as the time axis moved. This visual representation of the changing values provides the observer with a continually developing picture of how the values changed. Preserved on the screen during the 10 minutes time span, the changing values were depicted as curving and bending lines. The graphs resembled the paper roll based machine plots from before computers and screens, where a pen moving in one axis across a moving paper strip, inscribed time specific values into a two dimensional visual interface by leaving a visual trace of the historical development of the values. In the same vein we can see that the visual interface to the adaptive regulation PLC preserved the historical development of chosen values by plotting them on a moving time axis.

The two-dimensional plot re-presents an interpretation of how the values had just changed through how the lines can be seen to curve. The time window of the plot that we can see on the figure 7.11 and even clearer in figure 7.12., was 10 minutes. What had just happened in terms of torque level and differential speed appeared at the right side of the screen, and then moved to the left side, before leaving the visual plot after 10 minutes. This simple plot presented a visual interpretation of the speed by which the values were changing, which was visualized by the steepness of the curves. This did not only express whether a value was going up or down, but also how fast it was climbing or falling. A vertical cut in the plot would tell the values of the torque and the differential speed at that specific moment in time. To preserve some of these 10 minutes time slots, screenshots were made and saved on the hard drive of the laptop.

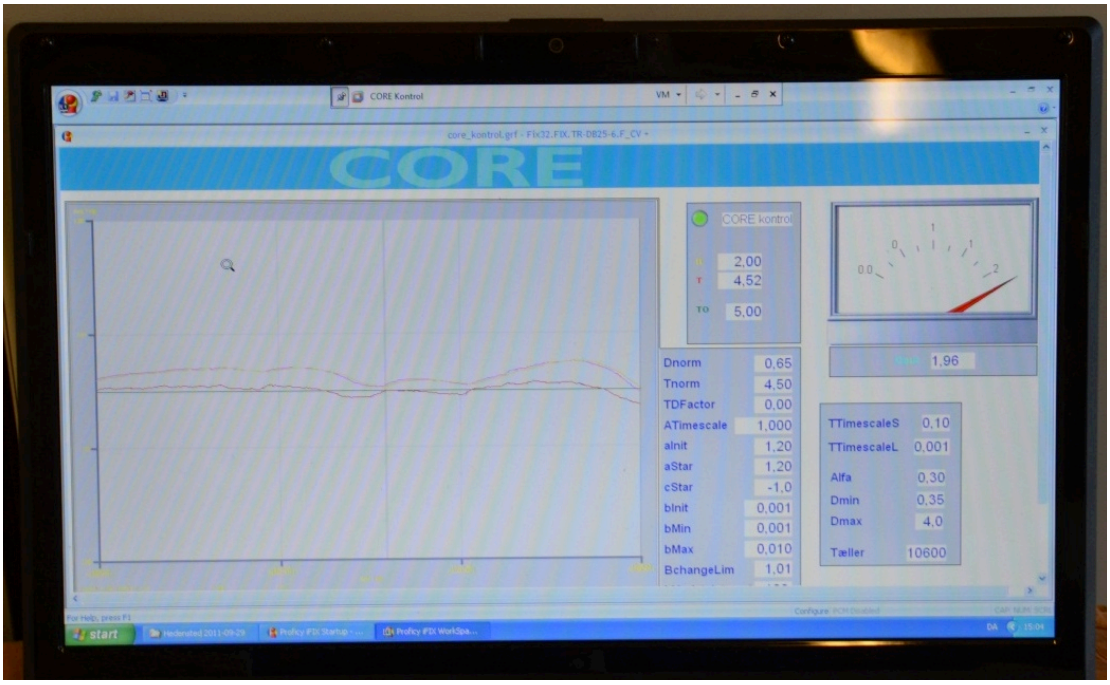
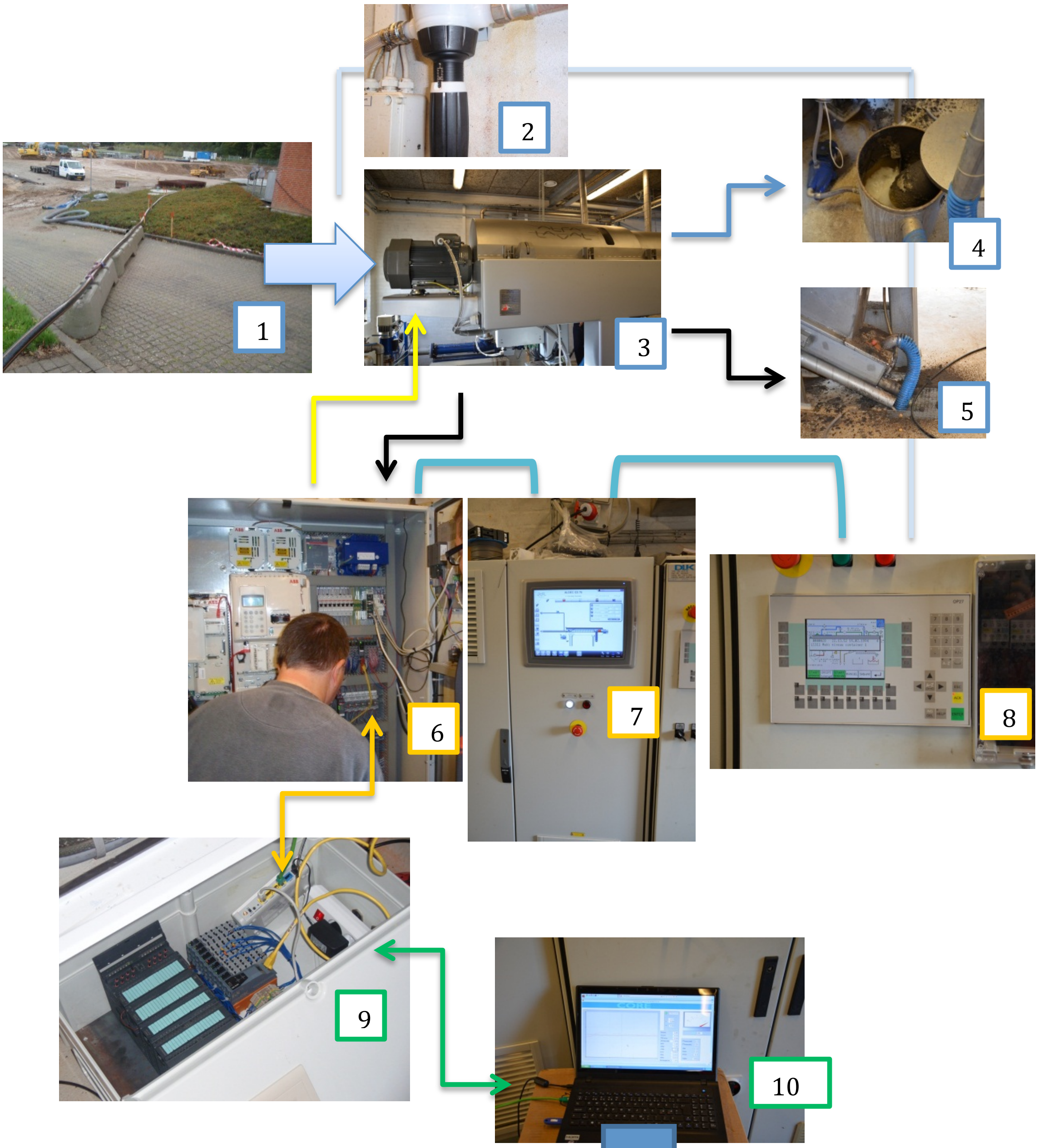


Figure 7.12: The screen of the lap top showing an on-going plot of the regulation model in action. Picture by Author, fall 2011.

Figure 7.12 shows the screen of laptop. This screenshot is not only a re-presentation of the adaptively regulated decantation process that occurred at the time the picture was taken, as well as the working connection that was established through the field expedition. The screenshot also re-presents the output of the expedition. This re-presentation can be seen to inscribe, preserve, and make mobile what was accomplished at the field expedition. We can thus understand the screenshot as an immutable mobile that would form part of a greater body of inscriptions produced through similar test setups. The purpose of producing this body of documentation was to analyse the performance of the regulator. This served had two different goals. One goal was to further improve the regulator, while the other was to document the regulator's worth before potential customers.

For the regulation consultants and for the decanter supplier these screenshots are the content by which they later would be able to analyse the outcome of this decanter implementation as a case of what the adaptive regulator could offer future decanter products. To narrow down the scope of the field expedition and all the efforts that was conducted to test the adaptive regulation of the decanter at Hedensted, the activities can be understood as a process of numerous translations at different levels, making mathematics into plots. In the ethnography of the Boa Vista expedition, Latour emphasises the role of visual outputs. "I have never followed a science, rich or poor, hard or soft, hot or cold, whose moment of truth was no found on a one- or two-meter-square flat surface that a researcher with pen in the hand could carefully inspect." (Latour 1999, p. 53). The outputs of the testing we have traced here at Hedensted were plots documenting how certain parameters fluctuated throughout the process (see Figure 7.11, 12, and 13). These outputs also made what otherwise would be inaccessible, accessible. By comparing examples of when the existing decanter steering was in control and when the adaptive regulator PLC steers the process, made it possible to compare the two cases and evaluate the new potential regulation. This part of the implementation process is one of inscribing the merits of the model-operation in action when it steered the separation process. The plots that were produced were re-presentative outputs of the testing. They thereby yielded great importance because they became the immutable mobiles (Latour 1986), which in another place and time, can speak for what the adaptive regulator was capable of. The plots can show for others what the regulator was made capable to perform during the test setup. The potential outcomes of these assessments could for instance be used to evaluate the possibilities for further adjustments and developments of the regulator software.

The Illustration Figure 12 on the next page shows the main technical functions behind the decantation sub-process at the wastewater facility. For the sake of simplicity the human functions supporting and realising these technical functions are not included explicitly though they has to be considered equally important for the whole arrangement to produce the tests and the documentation to support further developments and integrations of regulation models in wild settings. Each partial technical function has been numbered as reference to the attached explanation. The numbers are grouped according to their colours where the blue numbers refer to the foundational separation process which translates wastewater: (1) with an added polymeric material: (2) through the decanter: (3) into cleaner wastewater: (4) and sludge: (5). The yellow numbers refer to steering functions, where the frequency converter: (6) is driving the decanter engine: (3 again). The two touch screen: (7) in the middle of the illustration also includes the integrated decanter steering, and the facility steering system: (8) to the right in the illustration. The green numbers refer to the test material brought to the site for the testing which consists of the suitcase: (9) housing the adaptive regulator PLC and its connection interfaces, and the laptop: (10) which is the visual interface showing the screen plots: (11).



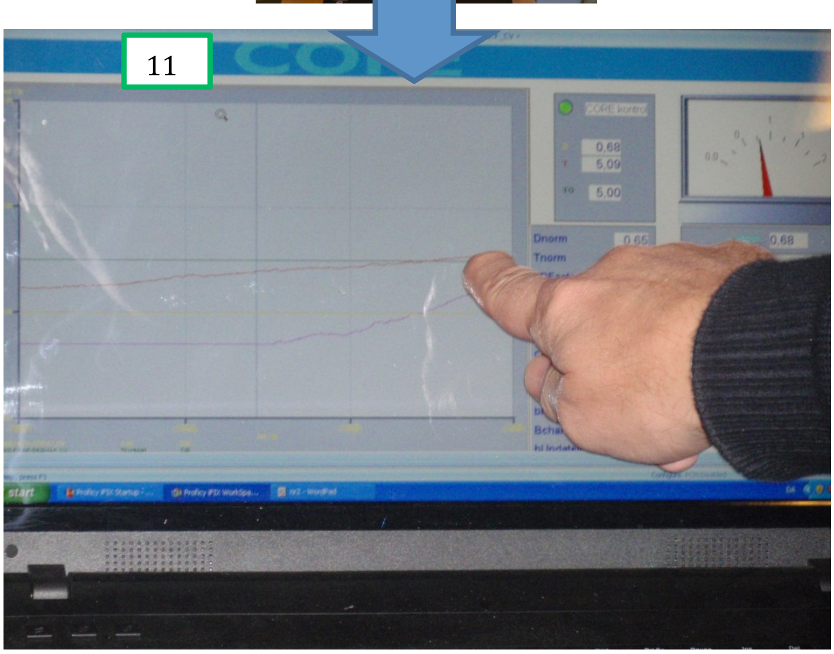


Figure 7.13: Illustration of the technical network in which the CORE regulator is tested. Illustration by Author, 2011.

Making a Model Wild

What has been described and exemplified through this chapter is a sample of the realities needed in order to make a model operational. To do so the mathematical model has been translated from a mathematical expression through a cascade of adaptive steps into an existing operational technological setting. For the sake of simplicity, I have listed the four stages of the translation from the abstract to the concrete below:

Codification of Model:

From an abstract mathematical expression the model was first re-coded into a programming language that was transferable to a PLC from which it could work as a regulator.

Model Distribution:

The PLC carrying the regulator was then translated to be mobile and transportable by being arranged in a practical suitcase with a variety of interface modules in order to make it able to connect with the process equipment that it should later steer.

Model Operationalization:

In order to make the model integrate and steer the process equipment at Hedensted wastewater facility, the model needed to be operationally connected to the decanter. This translation was of a different character than the previous two. This translation was purely dependent on the capabilities and tools of the two present specialist domains. The successfulness relied on both domains abilities to unfold and together align the present hardware and software, in order to enable the model ntegrate with the particular settings at Hedensted.

Inscribing Model Operation:

During the integration of the new regulator, the results needed to be preserved which called for yet another translation in order to inscribe the whole event into graphical plots.

Translation directionality

In relation to the translations, as described by Latour, in the forest of Boa Vista, the translations at Hedensted had many similarities. Both the cascades of translations in the Boa Vista forest and the cascade of translations at Hedensted, relied at first, on a preparatory coding translating matter and form. A small piece of the wild forest in Boa Vista was wrapped into numbers and codes, and the mathematical expression was translated into a program. Where the stark difference between the early translations resided, was in the direction of the translations. The wild Boa Vista forest was extracted as “matter” that Edileusa translated into “form” by dividing it into a Cartesian grid, thus enabling lighter and more mobile samples to be subtracted. The mathematical function that on the other hand was the starting point for the model we witnessed the implementation of in Hedensted, was translated into computational codes that were compatible with the chosen PLC. Although it is difficult to speak of weight when abstract matter like mathematics is under the magnifying glass, the principal dichotomy between particularity and generality still seems valid. When mathematics was translated into a specific computer code it was made more material, more particular and less universal. If we examine the matter of mathematics and that of computer code, we can understand the abstract language of mathematics to become more concrete, when translated into a specific computer code. Translating mathematics into a long sequence of binary code also made it depend on being stored on, and processed by, adequate hardware. We find both the general quality of abstract mathematics and the particular quality of matter at Boa Vista and Hedensted, but the direction of the two translational processes was opposite. Contrary to Latour's description of the field scientists' practice, the regulation model implementation made the mathematical model heavier, in order to operationalize it at the particular and local setting at the wastewater facility.

The opposite direction of the translations was also evident for the translations dealing with preservation and mobility in Hedensted, compared to those performed in Boa Vista. In Boa Vista the efforts invested in sampling, drying and pressing plants and digging up soil and to place it into dedicated small chambers in the pedocomparator were to subtract and cultivate evidence from the wild forest. At Hedensted the efforts invested in programming the PLC and arranging it in a suitcase with numerous interface possibilities, were to bring the otherwise abstract model closer to the wild settings of the wastewater facility. The reason we found for these opposite directions of otherwise similar types of translations, related to the different purposes of the two expeditions. The scientists in Latour´s ethnography did not enter Boa Vista to directly change the course of the changes in vegetation. The practitioners I followed to Hedensted were exactly to affect the course of the separation process in order to drain more wastewater from the sludge. These opposite interests called for opposite translations. A small piece of the wild forest of Boa Vista was translated into millimetre-ruled paper, and abstract mathematical expression was translated into graphical re-presentations of a better-controlled separation process. If the wild forest was cultivated and tamed through the cascade of translations described by Latour, the tamed mathematical model was made wild through as cascade of translations that enabled it to inhabit and be operationalized in a particular habitat at the wastewater facility.

Chapter Eight

Discussion

Intended and Unintended Displacement Effects of the Regulation Project

If we are to believe the claims from technical universities, mathematics possess an incredible ability to accurately depict our surroundings and thereby help us to understand and master almost anything about society. Consequently this could appear true if we look at the rapidly increasing amount of computerised technology that surrounds us, or even have been implanted into our bodies as medical enhancements such as pacemakers. Even more so it seems to be the case if we try to locate the laboratories that once were the backbone of engineering educations, but now largely have been replaced by computer environments such as data-bars and servers (Jørgensen & Valdamarra, 2012). Surely computerised mathematics has affected our society in more ways that we can ever hope to fully grasp. But what empirical and analytical tools do we have to trace the ways in which our society is displaced into an increasingly mathematized society and the multitudes of effects this produces? The purpose with this discussion chapter is to trace how the regulation project has displaced the factory's production into a mathematically regulated state as an example of how computerised mathematics are shaping our society. By proposing a framework that can account for some of the major displacements of the regulation project, my aim is to demonstrate the usefulness of this framework as a new empirical and analytical tools for tracing and understanding how knowledge and technology transforms society.

While the previous empirical chapters respectively described the pre-regulation state of the factory and how it's production was translated into information; how that information was translated into a model; and finally how such a model was brought back and integrated into a factory, this chapter will bring together these perspectives to discuss how we can understand the wider effects of the project. For instance how we can understand representative mathematical modelling to have changed the production that surrounds what it re-presents. The aim with this overarching assessment of the regulation project is to qualify how we can discuss modelling's usefulness in the broader terms of how its mediations can be seen to rearrange scientific knowledge and societal problems. This perspective thereby seeks to bring into consideration both the re-presentational- and the technological dimension of models' usefulness. For instance what new knowledge has science produced about the factory and how has it changed the operational conditions for the machines and for the crew who operates them? By analysing the effects models produce through the distinctive environments they connect, this discussion aims to illustrate more broadly what impact simulation models can be seen to produce as part of changing a complex production setup. Through the case of the regulation project, this discussion thereby intends provide a novel perspective on how our contemporary society is mathematized through modelling, and how we can form useful criticism that appreciates instead of neglects this development.

As a starting point for tracing the effects that are relevant for the regulation project's participants, I will take departure in the project's official objective to utilise adaptive regulation to significantly improve energy-efficiency in the production. While a discussion could concentrate on whether or not these project-objectives have been justifiable, or whether and on what grounds, they can be seen as successful accomplishments or failures, this discussion will on the contrary focus on tracing the various ways the regulation project has displaced the production from one state onto another – where its energy-efficiency is just one aspect. For this we need an agnostic framework that is not limited by normative assessments about what can be seen as successes or failures, but instead can encompass such positions by placing them according to how they relate to different identifiable displacements of some state of the production into another. The intention is thereby twofold by both pursuing to develop an analytical framework that is capable of unfolding the regulation project in new interesting directions, and by this also to produce new recognitions about regulation project. In this framework the regulation project can be seen as an example of how the introduction of new technology produces a range of interrelated displacements of that particular setup into a new one. While some of the generated effects were planned in order to achieve certain declared goals like improving energy-efficiency, others can be seen as unintended consequences related to how the declared goals were reached. For example the need for knowhow about the maintenance of the new regulation technology can for example be seen as an unintended, but related consequence of improving the energy-efficiency through new regulation solutions. The idea is that we can better appreciate and learn from the regulation project as a multiplex event, by placing its wider range of intended and unintended effects into a framework where they can be juxtaposed as various interrelated displacements of one configuration into another.

The framework I propose for the analysis of the regulation case consists of three dimensions of displacement that each are related to different questions. Tracing the displacements of various elements from one discrete situation to another can thereby tell us something about the event that has occurred by illustrating what differences that it has generated between the two situations. Firstly there is the epistemological dimension that concerns the question about what knowledge that has been produced; what ignorance has been displaced into what certainty and vice versa. Secondly there is the question about agency. This dimension concerns how power has been displaced from one form associated to one set of actors and onto another form associated with another set of actors; how has the ability to act been displaced from whom to whom? What and who have become weaker in some way and what and who have become stronger in another way. Thirdly we have the question about dependences and risks. This dimension concerns how dependence has been displaced and thereby moved risk from one set of issues onto another set of issues in the production. If we hold together these three related aspects of displacement, we are able to compare the situation before with that after the regulation project has occurred. This comparison provides us with two lists; one list with all the characteristics of the initial situation before the regulation project; and another list with all the characteristics of the situation after the project. The benefit of this approach is that we can illustrate the event's performance through the detectable variance between the two situations. In the new situation that is the result of the event, we can now examine its range of consequences by organising them according to the aforementioned three different aspects of displacement. An important feature of these aspects of displacement is that while they are thematically organised, they have neither fixed end points nor quantitative comparable measures of value. Whatever has happened from one situation to another, its assessment, as a displacement is purely qualitative in terms of as what kind of displacement it can be identified and appreciated. In this sense, the ways in which an event can be described as certain displacements, from one situation to another, produce that event into different realities. And the ways those realities are intertwined and seen to relate, can thereby tell us something new about both the particular event, and the nature of those realities during this event. In the case of the aforementioned three aspects of displacement, we can thereby investigate how the natures of knowledge, power, and risk change throughout their dynamical relationships during the event.

Another important objective concerning the two lists of characteristics is to look for both the intended and the unintended displacements of elements from the list before to those of that after the event. While a protagonist view on the event would choose to focus on its intended effects, a critical view could pick out the unintended and unwanted effects of the same event. Consequently, protagonists and critiques can easily pick and choose from the event's various effects to make two completely separate lists of objects where each list support opposite claims. To face this potential pitfall of a critique that is driven by pre-existing positions, the resulting situation of the event can also be made into two lists. One list that features all the intended effects of the event, and another that features all the unintended but nevertheless related effects. The purpose of these two lists is, in opposition to the position driven critique, to connect these two contrasting positions by tracing their interrelatedness as different effects caused by the same event. The aim is thereby to avoid the restrictions of either having to support or be against an event and instead connect the multitudes of effects that are inevitably connected to the same event.

If we pair the intended/unintended dichotomy with the three types of displacement, we get six categories. We thus end up with an intended- and an unintended category for each type of displacement. While three of the categories contain the intended effects that respectively are associated with each of the three types of displacement, the other three contain the unintended effects associated with the same three types of displacement. When relating the list of intentious- and unintentious effects we can take one characteristic, say the intended effect of new certainty and then look for all the related indented and -unintended effects in the remaining 5 categories; what new ignorance has it sparked, what new dependency does this translate into, or who has become weaker when others have become stronger. To do this we need to look at all documented- and potential relations whether they are internal to a new machination of things, the way people alter their relations to a technology, or reorganise their work around the function of a new technology. The analytical agenda is thereby to be attentive to effects that are equally related to nature and society while simultaneously remaining broadly interested, no matter whether these effects have been intended, expected, or successful, or not. In this quest the analysis takes inspiration form the principles of generalised symmetry (Callon 1991, Latour, 1991/1993) by wanting to account for both intended and unintended effects through the same displacements. The three types of displacement are to be seen as both empirical- and analytical tools that help us to appreciate a broader range of interrelated effects that are associated with the development and implementation of technology. Whether a technological project becomes known as a success or as a failure has, in this perspective, more to do with whether the protagonist view or the critical view has gained more strength to speak than the other. However in this analysis we look neither for successes nor for failures, but for traceable effects to appreciate the eventfulness of the regulation project as an event of displacement. In the following I will demonstrate these three dimensions of displacement, their interrelated effects and the questions we can raise from them through the case of the regulation project.

Displacements onto New kinds of Certainties and Ignorance; the Question of Knowledge

One of the central aspects in the regulation project's method was to use different empirical approaches to analyse the factory's various production processes. The goal was to understand how the factory's production depended on various measurable process-parameters that could be used for automated regulation. The basis for the regulation project was a production that was run by operators, who from their practical experience knew how to run the machinery in their respective production domains. Being a group that shares overall working routines and as a whole holds the responsibility for running the production we can see the operators at the factory to form what Lave and Wenger (1991) termed as a community of practice. Within the operators' community of practice they played different roles according to which production subdomains they belonged. Although the operators during their introductory training had been taught by experienced operators about how to specifically operate and service the particular machines, there was no uniform understanding among the operators about how to run the machinery best. While we can see the operators to stand out as a distinct group among the factory's staff, by means of their shared work form –having the same types of responsibilities, work hours, and physical surroundings at the factory, the operators differed internally as a group, by the machines they operated. The production's organisational division into three subdomains meant that the operators within each domain shared specific machines, tasks, and dedicated production responsibilities such as raw product reception, or packing of finished product –all depending on what domain they belonged to. In this regard we can see the operators to form smaller and more closely tied communities of practice around the specific tasks and the particular machines they operated within their respective production domains. By working with the same machines, the operators shared specific, practical, and operational knowledge about 'how to get things done' within their local domain of the production. Gilbert Ryle (1949) distinguishes this dispositive knowledge as 'know how' that opposed to declarative knowledge, which he calls 'knowing that', is practical in nature. Dispositive knowledge is thereby learned through practice and entails the ability to respond to actual situations and get things done. Know how is specific to the socio-material environment in which it is learned and therefor must be seen as "tied" locally to that environment. In other words know how "sticks" to the environment and the practice through which it is produced and distributed (Hutchins, 1991). Declarative knowledge on the other hand is abstract in form, and is as the name suggests, declared on examination. Social learning theorists point out that 'Knowing how' is often dismissed as 'mere' practical knowledge and wrongly assumed to be inferior to theoretical knowledge (Brown and Duguid, 2001). On the basis that thinking and theorising are practical doings they entail know how just as any other practice –whether physical things are operated directly or through abstract re-presentations. Theorising is therefore realised through know how that, as any other doing, is specific, local, and tied to that practice. Know how that is tied to and therefore concrete to the members of a specific practice will therefore often seem abstract or unintelligible to non-members because they do not share what makes it comprehendible within that practice. Declared knowledge is less challenging to share than the dispositive kind because 'knowing that' conforms to forms that are shared –such as explicit spoken or visual language. Declared knowledge is therefore the typical form of exchange in and between practices although it does not directly resemble the 'know how' on which it builds either in form or in content. However, the ability to set declared knowledge into action entails know how that is specific to the practice in which it is to be deployed.

While the operators' know how was central for the practical machine level operation in the production, conveying it into regulation solutions was challenging in several ways. First of all, because it was tied to the complicated activity of operating specific machinery, declaring it as 'knowing that' would not only mean to rid it from the very environment in which it was realised, but also to transform it completely into something that was comprehendible for someone outside that specific practice. Such transformation would inevitably mean that the operators' knowledge had to loose its specificity as operational know how in order to gain another specificity, as declared regulation knowledge. This "abstraction" from local operation in order to be "concretised" for regulation, gave rise to another challenge that related to the diverse and local character of the operators' 'know how'. Based on experiences that were produced within the boundaries of each production subdomain and often related to single machines, this know how had little to say about the production in its entirety. The outset for the regulation development was therefore a lack of knowledge on how to run the production machinery for optimal transversal effect across the production domains. In order to develop efficient regulation solutions the project needed to convert this ignorance into certainty.

One approach was to interview the experienced operators about how they ran their respective production domains. By doing this in cooperation with the factory's management, the coordinator extracted and unified the operators' individual accounts as declared experiences. This information comprised operator-accounts from the three production domains, and with these a wealth of different individual perceptions about the specific machines and the particular production domains. The coordinator thus came to see the production through the extensive information that he had collected from these interviews. What he soon realised was that there was severe divergence between the operators' individual and "local" views on the production. Although the operators' shared machines with other operators in their domain, they largely worked alone and thus developed their machine-experiences that way. The operators' accounts were therefore based on many years of individual, local, and particular experiences with the machines. Most operators had learned a very tacit hands-on approach to monitor the production. For instance the method many operators used to evaluate the important press production line was to take samples of the press cake and use their fingers to assess its quality. If the quality didn't feel right they would take measures such as increasing the feed to the press in order to give it more product to squeeze. The idea was to enable the press to build up more torque and thence make the press cake denser as a sign of better separation of liquids and solids. Such accounts were challenging to use in the regulation project for several reasons. Firstly, they relied on experienced operators' manual qualitatively assessments, which didn't fit into a scheme of automated quantitative computer calculated regulation. Secondly, the idea that denser press cake equalled better separation and better overall production yields had not been tested through reliable measurements. Thirdly, the measures that were typically taken to increase press torque conditioned other machine-processes which effects were not accounted for in any other way than how it affected the press' torque and the subjective assessment of the press cake's denseness. In other words, the regulation project coordinator had to considered the usefulness of much of the operational know how as limited by the operators' personal heuristics that were based on local machine-effects, which transversal production-effects remained largely unknown.

While the operators' accounts told something about how they ran the production and what they regarded as typical parameter-values for what they considered a healthy production, other sources of information were needed to shed light onto the transversal flows and effects in the production. For this, a large energy equation was developed based on analyses of data recorded from the production. This equation was made to assess where the largest energy consumptions were allocated in the production. Together with a flow-analysis that showed how the content of the ingoing product went through the production, the project coordinator could juxtapose energy consumptions, product-content flows, and operational parameters abstracted from the operators. These accounts needed to be drawn together to form a consistent "global" account of how the entire production should be run for best performance. The coordinator thus had to make both a transversal analysis of the entire production chain and an analysis of the individual machines. This was to understand how the single machines' processes, depended on how previous processes were run, and conditioned the subsequent processes. This extensive work resulted in the process description report that we observed the representative modellers to use as reference for their modelling of the thermo screw and the plate drier machines. An important recognition from the transversal process analysis was to narrow down on which machines that produced large transversal effects on the entire production. This was to be the machines for which the regulation project began to develop and implement regulation solutions.

If we compare the situation before the process description report to that after, we can see certain patterns in the displacement of certainty and ignorance.

Before the process analysis we had a situation where know how about the operation was distributed among the crew of operators and their various operational practices. In the situation after the process analysis certain aspects of this local know how were abstracted, compiled, compressed, and juxtaposed with production data in a report that provided the regulation project with a novel overview on the entirety of the production. Creating the report had displaced tactile 'know how' allocated among the operators and their particular practices into a unified description that amplified declarative 'knowing that' about the primary functions and key control parameters of the machine-processes. The operators' know how at the machine-level particularities of the factory's operation had thus been ridded from their tacit hands-on experiences and personal heuristics, to be displaced into new 'knowing that' about the entirety of the transversal factory operation in relation to its distribution of energy consumption and product flows. The answer to the question about what processes that were key to large overall production gains had been moved from uncertainty towards certainty. The new question for the regulation project to answer thus became about "how to" unlock those gains from these key processes. This new question thereby called for both new 'knowing that' about the how the machines' internal processes depended on various parameters and new 'know how' on how that knowledge could be harnessed through new regulation solutions. The questions about the machines' internal processes were about how these were physically conducted inside the machines and how the machines' key-parameters depended on other process parameters in order to become controllable? These questions point to what new ignorance the project had introduced through displacing certainty from local knowhow towards the entirety of the production. New knowledge had thus also fostered new questions. In a Donald Rumsfeld's rhetoric, we can see the project to have produced new known-knowns while at the same time pushing the boundary of what was known-unknowns further into what before was unknown-unknown territory. While the creation of the process description in a Latourian perspective can be seen as a giant matter into form manoeuvre, weaving operational sub-domain knowhow into a web of regulation knowledge that span across the entire production, the spaces that emerged inside the meshes of the web now raised new questions. With an exterior explanation of the transversal production processes the regulation project now faced a question about the interior operation of certain machines.

New Questions, new Ignorance, and new Methods for Displacing Certainty

The work associated with the process analysis had spread out an explanatory web across the production in which the machines were placed according to their specific function in the entire production line. While the internal processes of all the machines were associated with respective unanswered questions, some machines and thereby their associated unknowns had been identified as more important to answer than others. The thermo screw had become known to hold a central part by preparing the product for the press machine that would separate the product into either lucrative fat-containing fluids or less lucrative protein-containing solids. The thermo screw thereby became the known-unknown mesh of the entire web across the production that the regulation project first began to displace toward a known-known.

While the recorded production data and the operators' know how can largely be held responsible for the ability to establish the importance of the thermo screw, these sources were still exterior to the thermo screw and thus limited regarding the project's strive for certainty about the inner workings of the machine. Other measures were needed in order to answer this question. This is where the representative mathematical modelling method had something to offer. Like we witnessed in a previous chapter, the modellers' work was based on the aforementioned process description report. From this description the modellers abstracted information about what the thermo screw did and how it was physically constructed in order to determine the idealised physical processes with which to account for its physical operation. By shifting between the physical objects they knew the machine to consist of, into the functions they interpreted these objects to conduct, the modellers translated the machine into mathematized physics. By the same translation, the modellers can also be seen to displace the unknown inner workings of the machine into known physics. This displacement thus exchanged the ignorance about the actual machine's inner workings with the certainty of theoretical physics. While certainty in theoretical physics builds on the meticulous work of a vast scientific tradition, its particular relation to the actual thermo screw machines, on the other hand, was an entirely new link that the modellers had to establish. The move into theoretical physics can thus be understood to displace the general ignorance about the inner workings of the machine onto the particular connection of the machine's inner processes with the theoretical physics that the modellers deployed to re-present the machine. A new set of questions was thereby to be answered about the particular operational environment of the machines and the explanatory web of physical theory that the modellers had suspended across the machines' internal workings.

Following the aforementioned translations of physical machines into theoretical physics, the modellers faced a new kind of ignorance that they had to displace into a more certain explanation of the machines' interiors. The modellers' approach to realise this displacement was by expanding and concretising the models they created in the preceding stage. An initial step towards this displacement was to derive analytical mathematical expressions from the physical theorems with which, the modellers in the previous stage, had decided to re-present the machines' internal processes. By programming these analytical expressions into MATLAB models, the modellers could use their computer hardware to translate them into numerical expressions. Numerical expressions would enable the modellers to include numerical data on the actual machines and thereby fit their models' re-presentations to these machines. Largely because of the debugging that was required through these increasingly technical modelling stages, this displacement was not a straightforward process. An example of these extensive and time-consuming debugging activities was when the modellers discretised the thermo screw model. Discretisation is "the process by which simulationists turn differential equations, which relate continuous rates of change over infinitesimal intervals, into difference equations, which relate rates of change over finite, or discrete, intervals. The values that these difference equations give can then be calculated by a digital computer, from one discrete moment in time to the next." (Winsberg, 2010, p.8). As a result of the discretisation process, the modellers had created numerical models that were approximations of the analytical models. Ideally, these discretised numerical models would be as close as possible to the analytical models from which they were derived. Nonetheless, being approximations, some difference between the discretised models and their analytical models has to be accepted. One of the modellers told me that they typically could accept up to 1% deviation on the energy conservation equation. The point in making the mathematical model numerical was that it could be aligned with numerical data from its target machine and thereby brought closer to the actual machine it re-presented. Although mathematics is said to be a precise and concise language, this displacement however meant that some of the model's theoretical rigour had to be sacrificed when translating it from an analytical state to a numerical state. We can thus see the modellers to deliberately exchange analytical precision for numerical concreteness, in order to displace the certainty of theoretical physics closer to the machine's internal processes. However, after the discretisation, the numerical model showed unexpected behaviour and when checking the energy preservation equation, it manifested a 10-14% deviation from the analytical model. Technical issues like these made the modellers' practice oscillate back and forth between the white board and the computer. At the white board the modellers could better re-present, discuss, and modify the model's theoretical structure and issues that potentially related to their conceptual implementation of theory. For instance was the aforementioned large deviation on the energy equation a discretisation-artefact that related to their chosen re-presentation of fat's phase-transition? When at the computer, the modellers could implement what they had discovered at the drawing board by modifying the computer code and thus their computational implementation of the theories. Here, the modellers could for instance alter the discretisation intervals in an attempt to better trace the sudden change in the specific heat capacity of fat as it starts to smelt.

At this stage in their model construction, we can see the modellers to displace their numerical model's relation to theoretical physics from one discretised connection that entailed up to 14% deviation to another that showed less than 1 %. We can thus see the modellers' energy preservation equation as a concrete method for quantifying the uncertainty of their discretised models' theoretical re-presentation. Based on the principle of energy preservation, the modellers could thereby compare the different states of their models though how their re-presentations of energy deviated from each other. This manoeuvre displaced ignorance about a discretised model's relation to the governing physical theory on which it was built into a quantified uncertainty. Reducing this quantified deviation of energy between the analytical model and its discretised version provided the modellers with a measure for reducing uncertainty associated with the discretised models' relation to their analytical origin. Thus by displacing the model from one discretised state to another that manifested a better energy preservation, the modellers displaced an uncertain theoretical re-presentation into a more certain one. It is important to note that the modellers' original intent with translating the analytical model into a numerical model was to strengthen the mathematical model's relation to its target system. However, the consequence of displacing models from an analytical state of theoretical precision into a more concrete numerical state that was compatible with machine data, introduced uncertainty about the rigour of models' theoretical re-presentation. This uncertainty was then displaced into a quantified energy preservation deviation between the analytical and the numerical expressions, which according to the modellers' standards should be reduced to less than 1 %. These trade offs illustrate how the modellers during their model construction tries to manage ignorance and uncertainties about their models connection to theoretical physics and to their target systems. Through a series of displacements, the modellers work to make their models both stronger tied to their target systems through alignment with numerical data on the target system, while they at the same time try to maintain the models' connection to the theoretical physics. For the modellers their models become meaningful physical explanations of the machine processes when they, with reasonable certainty, connect both to the machines and to theoretical physics. We saw the modellers' approach to achieve this, was by oscillating between two distinct states of abstraction. At one state they worked on their theoretical re-presentations in the models and at the other state they worked on debugging their computational implementation of the models. Just as the operators, the modellers can be seen to rely on a great deal of practical know how in order to construct their mathematical models. The difference between the know how of the modellers and that of the operators is that the modellers get things done in order to produce new 'knowing that' –explanations, whereas the operators get things done in order to produce production. In a displacement perspective, we can see the modellers' stepwise concretisation of their models as a method to displace the ignorance associated with the connection between the models' theoretical foundation and their target systems. As part of this concretisation process, the modellers drew on numerical parameters of the machines' physical dimensions and their operational conditions to make their models stronger connected to these machines. The more concrete the models were made, the stronger they related to their target machines –the more they were believed to re-present the machines' internal processes. By computerising and discretising the models, they became compatible with recorded numerical production data from the factory. This would offer the modellers the opportunity to simulate the machine they re-presented with their computational model. Comparing simulated- and measured data could, if done successfully, displace much of the uncertainty regarding the model's ability to re-present its target system. It other words, this model validation method held the potential to displace the questions, which kept the meshes open in the explanatory web of theoretical physics, that was spread across the target machine's internal processes. The internal physical processes of the machine would thus be displaced from known-unknown towards known-known.

However, the practical challenge of producing data that demonstrated the model's representational worth, proved to be a challenge that was too big for the regulation project to accomplish. One major reason was that for the production data to be used for model validation, it would need to be controlled, coordinated and standardised in order to sufficiently comply with the model's parameters and their interrelatedness. That was particularly troublesome for the parameters that re-presented the raw product composition. Ideally, for model validation, a test should be run on perfectly controlled raw product compositions in order to know exactly what went into the machine. Comparing the input raw product compositions to the output of the machine and its energy consumption would provide the necessary data to validate the simulated data. While the internal processes of the machine would still remain an empirically inaccessible black box as a consequence of the very machine-parts that made them occur, a complete set of compatible input- and output datasets would demonstrate the predictable accuracy of the mathematized physical explanation. If the model could predict the machines' output data, based on its input data, it would prove to be a workable explanation that provided re-presentational insight to the machines' inner workings. Although it was doable for the factory to test periodic samples of the raw product, the ignorance associated with the unaccounted rest of the raw product that went into the machine, presented the imbalance on the energy equation as a minor issue in comparison. Model validation therefore never occurred in the regulation project. This might in a narrow epistemological view seem like a failure for the representational modellers. But in terms of the practical consequences for the regulation project, it was insignificant, because for them, the true value of the model was not representational, but operational.

This distinction between representational- and operational value will become clear in the subsequent section, but before that, let us make a short recapture of how we can see the regulation project to have displaced certainty and ignorance. First we had a situation before the regulation project where the operators ran the factory based on their respective partial, local and tacit know how. For the purpose of process optimisation through automated regulation, this know how was considered limited in regard to the development of an overarching operational scheme that could optimise transversal production yields. The preparations related to the making of the process description report was in this perspective how the regulation project managed to displace the entirety of the transversal production form a state of ignorance towards one of certainty. The report can be seen to displace the operators' "local certainty" concerning their respective subdomains into a "global certainty" that enabled the regulation project to comprehend the transversal processes of the entire production. Until that point, the process analysis had mainly been empirically based on interviews and production data. Because the new question to answer was about the internal workings of the machines, of which they had no direct empirical access, the new issue to solve was of a radically different kind. Here mathematical modelling's special ability came into effect by offering to mediate between physical theory and a target system for which only sparse data existed. Through abstractions of what was known about the machines, the modellers produced re-presentations of the machines and their internal processes that likewise re-presented a displacement of the questions about these processes into the explanatory certainty of theoretical physical theorems. This translated the ignorance about what went on inside a specific machine into questions about how theoretical physics could be made to speak of these exact machines. While physical theories each speak of an idealised class of phenomena, the detectable behaviour of the actual machines at the factory did not fit such idealised patterns of theoretical prediction. The modellers' approach to displace this explanatory misfit between theory and machine was to combine several theoretical explanans in their models. In the case of the plate drier machine, they paired the general law of heat conduction with the general law of flow distribution, in order to re-present both how product was moved and heated through the machine. By drawing together physical theories into a combination of explanans, the modellers made the model more concrete in order to better match the particularities of the machines. The following computerisation of the models enabled the modellers to include numerical data from the production and thereby further align their models with the particular machines they re-presented. We can thus see the overall work process to first displace a lack of focus on the entirety of the production. On this basis, the regulation project chose specific machines which internal workings they displaced into the certainty of physical theory. As an effect of how the project displaced certainty from one situation to another, we can also see how they displaced ignorance between these two situations. Through data collection the project first displaced ignorance about the entirety of the production to ignorance about the internal workings of single machines. Then by the means of mathematical machine modelling this ignorance about the internal workings of the machines was displaced to ignorance about the concrete connection between target machines and the theoretical physics that was deployed to re-present them. While this epistemological question was never fully settled through data based model validation, the models' predictions were nevertheless used by the regulation project to develop operational regulators. My observation showed that the receivers of the representative models thereby deemed their predictable certainty adequate for regulation before the representative modellers themselves became sufficiently certain about the models' re-presentational worth. The models' re-presentational certainty thus depended on their usage. Their uncertainties were deemed acceptable for operational regulation but still unacceptable for a high-ranking publication for natural scientific peers.

The pattern we can recognise from these displacements is that the same events generated both certainty and ignorance simultaneously. If answers are said to settle questions, the regulation project's achievements instead appears to displace questions rather than produce final answers. What we learn from the regulation case is that its knowledge practice instead of dissolving uncertainty and ignorance, displace it from what according to the project participants is seen as critical areas to less critical areas. By displacing ignorance to areas that were seen as less critical, the project used their new knowledge to support forward-looking decisions like which machines to prioritise out of the entire production. The regulation project's continual manoeuvres of displacing ignorance can thereby be understood as means to produce novel opportunities for action. Epistemologically the regulation project can in this perspective be seen to navigate between ignorance and certainty, continually displacing one for the other to create new opportunities in order to manage what is unknown. By repeatedly displacing ignorance and uncertainty onto what they saw as less critical issues, the project provided for new kinds of decisions about where to move their attention next, in order to translate the project's overall objectives into more doable subsidiary goals. We can thus see the displacement of ignorance and certainty to have supported the project's decision-making by moving the boundaries between what was known-knowns, known-unknowns, and unknown-unknowns. While expanding the explanatory web across the factory's production, the project navigated between the meshes that it assessed to contain questions that were beneficial to further displace into less critical issues. The regulation project can thereby be understood to displace their view on the factory from seeing it as a big, messy, and confusing place into a reduced and organised process description with which they made the factory manageable in terms of deciding how they saw it doable to optimise. On the specific machine-level, what to the regulation project had previously been internally hidden processes, their modelling activities had translated into visibly tangible simulated re-presentations. With the modellers' representational models at their disposal, the project had attained re-presentational tools that produced predictions on the machines' behaviour under different operational conditions. While these predictions never got verified, their re-presentational effect to the regulation project was to make the machines more manageable by guiding adjustment of operational regulation parameters to encounter varying operational conditions. In this view we can see the regulation project's displacements from ignorance towards certainty as important to their ability to act, make decisions and solutions, and thus central to how they displaced agency throughout the project.

Displacement onto New kinds of Certainty becomes Displacement of Agency and Power

This paragraph concerns the implementation of the new adaptive regulation models at the factory and how this affected the distribution of agency in the surrounding production setup. The factory at which the regulation models were to be implemented was already a place of great multiplicity. The ecology of the factory consisted of a variety of process machinery, transport installations, information infrastructures, and different groups of staff with dedicated responsibilities. All these entities were part of an organisational setup and, as a whole, responsible for the entire ecology to come together as a competitive production that could survive in the market for slaughter plants' waist products. Compared to the ecology of the factory, the adaptive regulation technology made up a small and simple technical entity. Despite the vast difference in scale between the factory and the new regulation models, the intention with these models was however to improve the entire factory's production and thereby its competitiveness. Put in a different way, no matter how these regulation models were supposed to integrate with the factory, they were expected to displace the performance of the entire ecology into a more competitive one by increasing production yields and energy-efficiency.

The new regulation technology was in essence designed to offer improved automated control over production machinery. The regulation models worked by forming a closed feedback control loop based on the sensed behaviour of a machine-produced error signal that steered the machine's behaviour towards the desired set-value. In this view we can see the models as being designed to operate within a purely techno-scientific control paradigm. However, the actual environment that these regulators were intended to work within, extended far beyond what techno-scientific control theory accounts for. If we instead take the great diversity of the control-loop implementations' surrounding environment into account, we can see that its technological control agenda formed just one part of an overall control strategy. In order to grasp how the introduction of these new adaptive regulators produced effects in their new surroundings, we first of all need to get a better idea of what kind of organisational environment its control-loop technology was introduced into. We will therefore now take a look at the factory's organisational ecology to see how the models' technical control agenda fitted into the organisation's overarching control strategy.

While the ability to be competitive is one of the most important premises for conducting any business, how to do so best is on the other hand a never-ending discussion. Inspired by Taylor's work on early industrialised mass-production, traditional management literature promoted the idea that there should be one best way to design organisations. Later management literature promoted the idea that there are many 'best' ways in organisational design depending on size, the nature of the task and market conditions. Moverover, organisational design is fraught with inherent conflicts and dilemmas (Mintzberg, 1983). However, no matter how we look at a business' organisation, it is always its management that holds the final responsibility for its operation. A business at the size of the factory in this case, would be totally incomprehensible if not responsibilities were delegated through an organisation. As Mintzberg (1983) describes in his opening paragraph of *Structures in fives – Designing effective organizations,* already when reaching the size of a few individuals, efficient coordination of work cannot rely alone on simple mechanisms of informal communication. In his view an organisation's delegation of tasks is therefore an important tool for its management to develop and maintain their business' competitiveness. Where this becomes interesting in a displacement perspective is that delegation of responsibilities and tasks is inseparable from displacing power, agency, and thereby dependences. For instance, if someone, somewhere critical at the factory, makes a significant error, the whole production, and thereby the whole business together with its management and external investors, could be jeopardised. Where something is at stake, a responsible management therefore has to make sure that agency is delegated together with some form of control-mechanism that enables the management to monitor and enforce some kind of control on how its distributed agency translates into action and effects. Mintzberg (1983) refers to these primary organisational functions as *delegation* and *coordination* of work. How to best conduct a business in this intra-organisational perspective then crystalizes into two different major questions; one is how to best delegate responsibilities and thereby agency? –The other is how best to monitor and control how these responsibilities and their associated power are conducted? Essentially the delegation of responsibilities are to provide the means for things to get done –hereunder the development of the necessary decentralised know how. Control-mechanisms, on the other hand, are means for the management to attain the necessary informational feedback that makes them the centre of the organisation that can monitor and adjust how things are done at the periphery of the organisation. At the factory we can see the central management to delegate the overall production responsibility to the production manager who again delegates the operational responsibility to the crew of operators who are divided into the three production sub-domains. We can also see the operators to delegate most of the practical production to their machines, and other technological assistances, that turn the raw product into output product, and helps them to monitor and control this event. Being based on centralised control and decentralised work processes that are standardised and routinized around the production machinery, the factory's organisation resembles a class example of Mintzberg's (1983) definition of "machine bureaucracy". According to Minzberg, the characteristic attributes of machine bureaucracies are "highly specialised, routine operating tasks, very formalised procedures in the operating core, a proliferation of rules, regulations, and formalised communication throughout the organisation; large sized units at the operating level; reliance on the functional basis for grouping tasks; relative centralised power for decision making; and an elaborative administrative structure with sharp distinction between line and staff." (p. 164) Mintzberg points out that the machine bureaucracy works best under stable conditions. Its rigid operational standardisation and the inherent distances between where problems occur and where they can be settled, makes machine bureaucracies little adaptable to change. In this organisational framing we can see the regulation project as an attempt to adjust and trim the factory's operational setup by redistributing managerial and operational roles between machinery and human staff. We can thus see the project's implementation of new regulation technology as a means to re-coordinate the functional structure of its organisation. The implementation of the new regulation technology can thereby be seen as an attempt to change the production conditions through what Mintzberg calls the "back door" of technology rather than the "front door of direct confrontation" between the factory's technical and social systems. While technological progress is typically seen as means to deliberate humans from technical constraints, we will examine exactly how the infusion of new regulation technology not only displaced agency and power onto technical relations – but also how it as a consequence displaced agency and dependency onto new social-technical relations at the factory.

From the comfort of their control room, the operators could monitor their production domains through their screens and coordinate with neighbouring domains through the operators that sat next to them. By starting up, closing down, or adjusting their machines' set-values, the operators exercised control over how their machinery conducted its delegated tasks. The operators' agency can thereby be seen as similar to that of the management in terms of having a central position, from where the work that was conducted at the periphery, could be monitored and adjusted. In this sense the operators, just like the various managers, form a kind of control-loop that monitors the behaviour of something within their responsibilities and adjusts it to produce the desired behaviour. The implementation of the new control-loop based regulation technology therefore has to be seen as an introduction of a new automated control-loop into the long chain of existing “organisational control-loops” that connected the machines’ production at the extreme periphery, with the intentions of the management at the extreme centre.

While the automation initiatives at the factory had brought the operators together in the control room, the pre-regulation production was still connected to the central management through a long chain of production data, screen projections, operators and the operational manager. In Mintzberg’s (1983) terminology, this can be seen as the factory’s “management information system” (MIS) that aggregates information up the hierarchal structure. For the central management to act upon the machine level of the production, they relied on these many decentralised levels of the organisational setup to circulate information into them, and executive orders out to the peripheral production. Put in another way, the ability of the central management to act at a distance, relied on a bulk of different translations –of which, only very few, would be under their direct control. In this pre-regulation setup, we can thus see agency, power, and dependences to be decentralised as a consequence of the delegation of responsibilities. More importantly, we can also see the management’s control-mechanisms to have a distributed modus of operandi that relied on the agency of several organisational levels. This distribution of organisational control-loops meant that both orders and information had to go through a number of translations, in order to circulate between the management and the production. These translations all entailed potential sources of distortion to both inward streaming information, and to outward streaming executive orders. Mintzberg (1983) problematizes the MIS for typically prioritising a late circulation of reports containing accumulated “hard” quantitative knowledge instead of timely “soft” qualitative knowledge – which specific information about current events are what management really needs in order to make good strategic decisions.

The pre-regulation organisation of the production therefore strongly depended on how the human operators conducted their agency through the machines. It was this dependence that the new adaptive control-loop regulation technology was supposed to displace. By offering to take over from the human operators the on-line set-value adjustment, as well as other important operational parameters, these new regulators promised to displace decentralised human agency into centralised and automated control-loop technology. The implementation of the adaptive regulator technology would thereby, if proven successful, become a new organisational actor that technologically centralised agency and dependences that beforehand had been decentralised parts of the production.

While we in the previous paragraph dealt with how the regulation project displaced certainty and ignorance in order to expand their explanatory web across the entire production, we can in this organisational perspective, see their new explanation of the production as a new foundation for centralised action. While this knowledge offered new insight to the production, and thereby a new foundation for managerial decision-making, the management's empowerment of that knowledge would, if not for the new agency of the regulation technology, still rely on the existing organisational setup and its distributed, and potentially distorted, control-mechanisms. The new adaptive regulation technology promised an alternative solution to that of the distributed control. The regulator approach was to automatize agency through control-loops, which meant that human agency, like that of the operators, would be prevented from directly influencing the machine operation. Decisions on how best to run the machinery would instead be settled centrally and encoded into the operational command codes of the new regulation models. This control scheme would allow the central management to enforce more direct control through the regulators' adjustable control-loop parameters. The new regulators thereby brought the central management closer to the machines by displacing their automated control-agency away from the peripheral operators' decisions and into the hands of the centralised management. The new insight to the production could now become centralised power through technologized control.

We can thereby see the introduction of the new regulators as a shift away from individual human operator control onto centralised technological control – and with this new technological control, a promise of production optimisation through increased production yields and energy-efficiency. If such optimisation were to be realised, a centralised control scheme would according to the management and the regulation project, be a prerequisite, because human influence was seen as synonymous with uncontrollable variance. By displacing operator control into technological regulator control should thereby avoid a "front door" confrontation between a new centralised technocratic optimisation and the plural "meanings of operation" among the operators. Implementing "intelligent regulators" is in this view a "back door" manoeuvre with the purpose of changing the production conditions without directly confronting the human operators. Earlier studies of industrial automation projects (Lundqvist, 1996) saw these to break with Taylorism by slimming down and decentralising organisations through displacing new and more fulfilling responsibilities onto human operators. However, the regulation project was instead about withdrawing agency from human operators by displacing it onto technological agents. Where the factory –as any other machine bureaucracy had been designed to operate through a delegation of narrowly defined functions to both its staff and its machinery, in order to make all its various elements mesh together as parts of one giant smoothly running machine, its human operators naturally became looked upon as the weak machine parts that jeopardised the efficiency of the entire machine. Naturally I say, because as we know, humans make up unreliable, unpredictable, and little controllable machine parts. In this perspective we can see the factory's organisational design to be a significant factor in how the optimisation analysis manifested the human operators as the weak links in the production. The weak machine parts that, in order to make the entire machine run more efficiently, should be replaced with proper, more reliable, machine parts –and what could be better for that job than carefully designed automated regulators? In this view, the new regulation technology promised to liberate the management from the unpredictable, unreliable, and unruly idiosyncrasy of the human operators by confining and restricting critical parts of their agency through means of new machine parts that should better fit the application.

Realising Regulation Model Agency

While we have just been through what role the new regulation models were intended to play in the overall organisational setup, we will now turn our empirical lens to how they changed the operators' practices. Earlier we traced the production of new knowledge about the factory's production processes. This paragraph however is about how that knowledge was implemented as new regulation technology that displaced power relations in the factory's organisational setup. The focus is thereby on how the new production process knowledge was translated into agency. The outset for the regulation project was as mentioned a production that was run by a crew of operators. Although the factory had already been automated, it was still the human operators who were responsible for its continual operation. We will therefore continue by looking further into the composition of the operators' work in order to better grasp what kind of control they performed on the process machinery, and how the new regulators' automated control displaced this onto a new configuration of work and process control.

In practical terms, the operators spent most of their work on servicing their production lines to keep them within appropriate operational conditions. This work entailed for example tasks like removing plastic boxes, or other unwanted objects, from the raw product supply containers, to make sure that the process flows didn't stall due to clotted pipes or other potential bottlenecks. This work also involved checking the energy supplies such as the boiler pressure and the electricity to make sure that these also were as they should be. During their 8 hours shifts, the operators went on numerous walks through their production lines to manually check and correct them if necessary. If something was not right they would try to correct it within their best abilities, or report malfunctioning or broken equipment to the factory's in-house repair shop. This work could take up most of their shifts, which often meant that the control room was left deserted, even though it housed three operators and monitored their three sub domains. Much of the operators' work thereby entailed direct physical contact with the production machinery, which they could not achieve from the comfortable distance of the control room. Only when back in the control room, and not being occupied with filling out repair forms to the repair shop, servicing craftsmen that had jobs to do in the production, or communicating with neighbouring operators, could the operators monitor the entire production through their screens. On the screens, the operators typically looked for anything out of the ordinary, which could show as small warning indicators on the screens' graphical re-presentations of the machinery. Once all these tasks were under control, there would finally be time for the operators to watch the numerical re-presentations of production parameters, and adjust set values if they felt that it was necessary. Due to the amount of other more pressing tasks, the operators generally only adjusted set values if it was a necessity for maintaining a good flow in the production. Consequently, 85 degrees was for example the most common temperature set value for the thermo screw because it ensured a stable and thus, in the eyes of the operators, unproblematic production-flow. It was first in the rare occasion when the operators adjusted operational parameters that we can see their work to move from maintaining and servicing to adjusting and optimising. From my observations of the operators' work we can thus see it to mainly consist of handling various practical hands-on issues in the production as they manifested themselves as problems. To better grasp how the operators' practice works, we can organise it hierarchically accordingly to what kinds of problems they have to take care of before others, in order to keep the production going. In this hierarchy, the practical maintenance that keeps the production machinery going would occupy the large and most important base. This base would be the basic premise for the whole production, and if something happened at this level, it had to be taken care of immediately. When this fundamental and often very troublesome level of problems was covered, for a while, the next level of problems to solve would be associated with matters of a more organisational character. These were issues such as communicating with the supply chain truck chauffeurs, repair craftsmen, and other operators whose areas of responsibility were somehow affected by the operators' work. Only when all these more present tasks were taken care of, could the operators begin to focus on adjusting the operational set-values of single machines. Such work was typically associated with the "highest" and most comfortable level of problems that the operators encountered and would only come into effect when all the more fundamental levels of problems were covered. From the perspective of the operators, it is therefore important to note that the "highest level" of problems came last when it came to their perceived importance. In the operators' 'meanings of operation', the more fundamental levels of problems always had to be taken care of before they could be bothered with luxurious issues such as fine-adjustments of operational set-values.

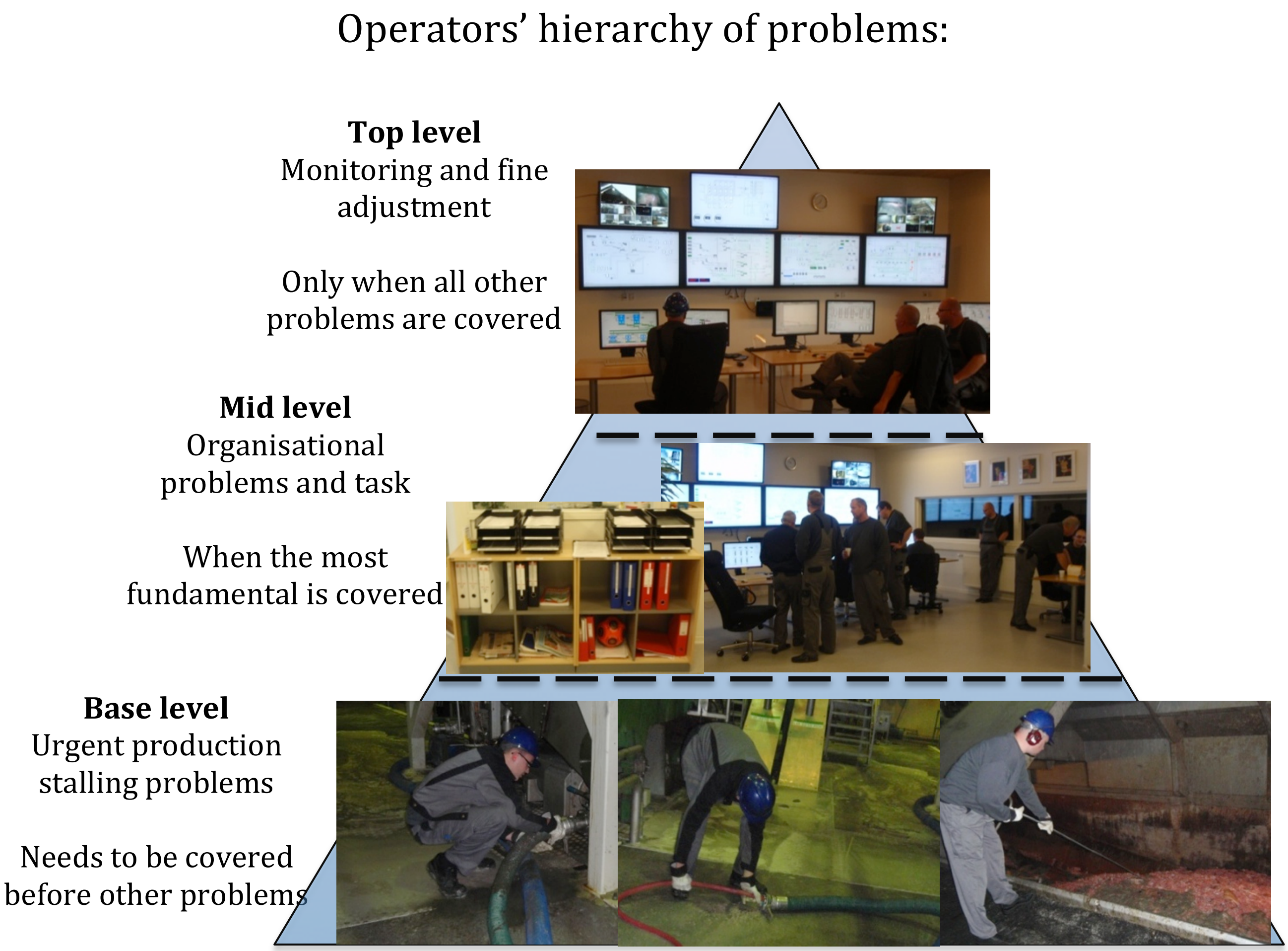


Figure 8.1: Operators' hierarchy of problems. Illustration by Author 2013.

From the operators' perspective, we can see set-value adjustment as a problem that only become meaningful to deal with when all the fundamental issues were covered. Additionally, it is important to note that when the operators felt the need to adjust set-values, they generally did so to acquire the most smooth and problem free operation of the production. Not necessarily what produced the most energy-efficient production nor the most lucrative production yields. Such ideas would instead be associated with a 'meaning of optimisation', which was a new mind-set that the regulation project brought to the factory and its management. Only the more experienced operators got to a point where they were able to develop extensive experience with adjusting machine operation. According to the operators, it took at least one year of hard learning by doing, within one sub domain alone, before a new operator could become reasonably "good" at operating that domain. Though still far from excellent, and primarily seen in the perspective of the operators' 'meanings of operation', where it was the practical tasks associated with keeping the production running smoothly and without problems, that were valued.

The efficiency of the pre-regulation production was therefore largely in the hands of operators who were mostly busy with other task than adjusting operational set-values. With the various views among the operators on how to run the production best, this situation, as it was, was far from ideal for realising process optimisation initiatives. In order to make the optimisation of the production practically doable, a subsidiary goal for the regulation project was therefore the aforementioned confinement of the operators' influence on the regulation of the production. The agency that was already implemented through the automation of the production was therefore to be extended further into the functional territory of the operators. The regulation project's approach to this was to integrate the new adaptive regulators into the already established information infrastructure of the automated production. The adaptive regulators were thereby the means of the regulation project to automatize more of the operators' work by taking over and running the set-value adjustment based on the representative mathematical models' predictions.

In the previous chapter we observed how the regulation project integrated an adaptive regulation model into a wastewater facility decanter. Integrating regulation models at the factory was also based on establishing operational connections between the models and the existing PLC based information architecture that steered the machines. While these regulation models all basically were the same adaptive core regulation model – whether they were used for decanter steering or for the thermo screw at the factory, they differed by their particular implementations. During implementation the models had to be adapted specifically to each machine they were to steer. This entailed adjustments for the specific connectivity of the existing PLCs at the factory, and the respective regulation parameters that were found critical for steering each machine optimally. By making the software- and hardware states of the model compatible with those of the target system, the models and the regulation knowledge they re-presented, could be grated agency through their implementation into the machinery. Setting up and adjusting the regulation model into the factory's automatized information architecture and switching over to its adaptive steering, we can see the production to move from 'human operator operation' to 'automated regulator optimisation'. This little switch – capable of such radical displacement of agency, figured as a little dot on the monitor screens next to the online data of the machines to which the regulator was implemented. In one position this switch would keep everything as it used to be, while in the other position, it would displace agency and power to the new regulator and everything it mathematically re-presented in terms of process optimisation. In one position the operators were in charge of setting the set-values for the machines' steering. In the other position, the adaptive regulation took over the set-value optimisation –thus cutting off the operators' influence on the production's energy efficiency. At the early phase of the implementation of the new adaptive regulation model, the operators were able to switch it on and off as a precaution if unforeseen problems should occur. Throughout the first month of the implementation, the operators repeatedly switched the adaptive regulation off. The operators thereby resisted to get enrolled in the new control scheme by manifesting their influence through switching off the new regulator. This was a problem for the regulation project because they needed to prove the merits of the new regulation scheme by recording its continuous operation in order to substantiate what gains it brought to the production. While the operators did not document when and why they turned off the regulator, an operator showed me a situation where he felt that the regulator had to be switched off. This situation occurred as the measured temperature continued to decrease even though the thermo screw ran at minimum speed where it conducts most heat energy to the product. This odd behaviour became problematic for the rest of the production because it stalled the flow in the production line. The operator told me that he in order to get the production back on track therefore had to switch the regulator off and go back to the original operation.

While the newly attained knowledge about the entirety of the production and the inner workings of its machinery had been translated into the regulation model's mathematics in order to become operationalized, its intended displacement of the operators' agency took an unforeseen turn. The operationalization of the mathematics conveyed into effects in the surrounding production that entailed a whole new set of uncertainties. Due to the premature phase of the regulation implementation, neither the operators nor the regulation implementers had any experience with how the regulators would respond to different variations in their new surroundings. Until the factory and the regulation project had more experience with the particularities of the implementations, these uncertainties would remain in the territory of unknown-unknowns. While the intention with the new regulators can be seen as part of an overall centralised control agenda that sought to minimise the unpredictability of the human operators, its practical implementation nevertheless meant that new dependences had to be established in order to control others. While the regulators' new technologically centralised control was intended to displace the production's dependence away from the human operators – it would inevitably displace that dependence onto something else. In this case that would be the technical operation of these regulators. All that enabled the regulators to connect with their working environment thereby became the new dependence of the production. This new operational setup thereby introduced new issues in the attempt to confine others. A crucial issue in this shift from human- to regulator based operation showed to be the intensified reliance on sensors. We will later see how the operators came to realise the entire production's reliance on a particular thermo sensor installation. Because the automatized regulators that now controlled the production solely depended on sensory input in order to adjust machine behaviour towards the indented, the production came to heavily rely on sensory performance. That reliance applied both to the sensors' accuracy and robustness. While the new regulation scheme sought to eliminate the "unruly" influence of human operators, it's potential for improved process control instead came to depend on the quality of the on-line process information. Ironically, the regulators that were means for more centralised control thereby introduced new and even further decentralised dependences such as the sensory connections. The reliance on human operators who occasionally could be seen in their control room, was now displaced further away onto the various sensors placed around on the machines – as well as onto the hardware and software that maintained the connection between the regulation models and the machines. While control became centralised, the dependences on which this control would materialise into intended effects, became as a consequence even more peripheral. We can thereby see the regulation project to produce a variety of new peripheral, yet potentially important, unkown-unknowns, as the newly attained known-knowns about production optimisation were materialised into technical solutions at the factory. Although mathematics according to technical universities is proclaimed to be a perfectly concise language that is capable of describing and predicting almost anything with great precision, the configuration of its particular implementation in mathematical models and in their surrounding environments which grant them agency, nevertheless prove to produce unpredictable effects. Mathematical knowledge may in isolation remain ideal, precise and thus predictable, but its power comes from the very connections that make it applications imperfect and unpredictable. The unpredictability of the regulation models' effects hereby redirects our analytical focus from the displacement of agency to the displacement of dependence and associated risks. The displacement of certainty and ignorance from one set of issues to another set of issues produced the potential for a redistribution of agency. However this redistribution produced yet another variety of dependences that translated into the emergence of new risks.

Displacement of Dependence and Risk

The displacement of agency and dependence from one production setup to another thus introduced new risks of which many were still unknown to the regulation project and the factory's management. While risk and risk management are enormous fields that extend far beyond that of organisational control strategy, I will for the sake of simplicity therefore focus on risk through the notion of instability. In this perspective risk is not only associated with the amount and different types of dependences that a system like the production setup relies on, but more so on the stability of those connections, and thus the conditions under which the setup remains stable or becomes unstable. As with any other technology, the regulators only function under certain conditions. The functional paradox of regulation is that while it is designed to make another entity's function less dependent of changes in its operational conditions, the function of a regulator itself remains itself dependent on its operational conditions. So while a regulator may effectively prevent variations in the input of a process from affecting its output, it will only be able do so if allowed by its own operational conditions. In terms of stability and risk, this means that while a new regulator may stabilise a production process, its ability to do so depends on the stability of its own operational conditions. In order to discuss how risks have been redistributed through the regulation project, we will therefore now look at how the project displaced stability and instability from one production setup to another.

While the new regulation technology freed the operators from the task of adjusting set values for the machines, it also displaced the production's dependences away from the human operators and onto the regulation models' new operational conditions. These new dependences thereby came to concern all conditions for every element that enabled the regulation models to act upon the machines. By displacing agency onto the models, the regulation project had also displaced the productions' dependences to all the relations that granted these models agency. The goal for the regulation project was thereby to exchange the instability associated with the reliance on human operators with a new, and expectedly more stable reliance on the technology that replaced the human agency. This can be seen as the regulation project's intended trade off – exchanging less controllable human variables with technological variables that were expected to be more controllable. Where dependence on the operators was problematic from a centralised point of view, because it was seen to entail uncontrollable human-conditions for process optimisation, the new adaptive regulation technology meant that transversal process optimisation could be controlled centrally and consistently through regulation parameters -hence a shift to centrally controlled process stability. This was therefore not only a tight delegation of tasks but also a tightly machinated control of the production stability. No matter who had the operator-shift, it would be the same regulation parameters that were in charge of the process optimisation. Achieving this stability was seen as central to the management in order to distribute and empower the new regulation knowledge at the factory.

Consequently the new adaptive regulation based operation could now control the production for 'transversal process optimisation' as a replacement for the previous 'local operation' of the human operators. The displacement of agency had thereby exchanged local operation that depended on individual human operators, with transversal optimisation that depended on a uniformly adjusted regulation technology. While this displacement of dependence was an important subsidiary goal for the regulation project to improve the energy efficiency of the production, the effects of this new optimisation scheme had yet to fully crystallise into the promised improvements. During the early implementation of the adaptive regulation, the operators did not completely enrol themselves in the new optimisation scheme, which they showed by repeatedly switching the new regulation off when they felt that it caused problems. In the cases where the thermo screw kept going slower due to a continually decreasing output temperature, the operators saw the new regulation as the bottleneck that caused the entire production to stall. If the thermo screw ran too slow, it provided less feed to the press, which resulted in decreased press-torque. At the same time this also became a problem regarding the time constraints for the storage of the received raw product that waited to be processed. All these issues added up to displace the new adaptive regulator from a means for process optimisation in the top level of the operators hierarchy of problems, to become a pressing problem in their foundational level of responsibility – together with issues such as clotted pipes and plastic boxes in the raw product intake. The switch made it fairly easy for the operators to solve this problem by turning off the adaptive regulator and adjusting the temperature set point down to make the thermo screw run faster. This however did not change what caused the regulator to produce this problematic machine behaviour. It only cut off the regulator's agency in order for the operators to prevent the production from stalling.

When realising how the operators reacted towards the new adaptive regulator, the regulation project together with the factory's management instructed the operators to leave the regulator on, in order to attain reliable production data on its operation. This can be seen as an attempt to displace an unstable and unpredictable use of the new regulator onto a stable use, which thereby would make the reported production data reflect the regulators' performance. While this instruction was intended to empower the new regulator, it did not in itself resolve its problem. The operators were now forced to look elsewhere to fix the situations it caused. It turned out that a new temperature-measuring device that had been installed to provide more accurate temperature readings for the thermo screw regulator, was sensitive to the rough operational conditions of the production environment. Because the accuracy of the temperature sensor was a central operational condition for the regulator, the project had chosen to submerge it in the hot run off liquid from the thermo screw. While this was done to fulfil the need for accuracy, the varying content of this fluid proved to become an unforeseen problem, as it tended to clot. When this clot reached the sensor, it separated the sensor from the hot run off liquid and caused conditions for faulty readings. This cause of sensory instability was discovered by one of the operators who during inspections had found that hosing the inside of this temperature measurement device with hot water restored the temperature readings of the thermo screw, and thereby brought the regulated machine behaviour back to normal – hence removed it from the operators' list of problems. While the regulation project had deemed the human operators a source for operational instability that had to be removed in order to generate conditions for optimal production, the very components that replaced the operators thus became themselves new sources of instability. The instability of the new production setup was however of a different kind than the instability that had been associated with the operator driven setup. While the operators' control was seen as instable because of their idiosyncrasies and preoccupation with other tasks than parameter adjustment, the new instability of the regulator driven operation instead entailed a variety of technical sources that first had to be recognised before they could be mended. However, where the operators' agency had been seen as problematical because the management could never know exactly how the individual operator would act, the operation of the regulation technology was very predictable –as long as it was kept within appropriate operational conditions. Outside those conditions, the only predictable thing about the regulators would be that they would not perform as expected. Only when within appropriate working conditions, would the regulators stabilise the machines' operation. However, the operators on the other hand, were not prone to the same sensitivities and would almost no matter the conditions, do what was within their power to stabilise the production. The agency of the operators and that of the regulators were therefore of such different kinds that they can better be seen to supplement, rather than replace, each other. From the perspective of risk, we can see the regulators and the operators to entail different kinds of stabilities and instabilities. While the regulators would produce great stability in the production when within their appropriate working conditions, the sensitive temperature sensor showed us that it was the operators who had the power and the creativity to identify and maintain such conditions. As what could seem to be a case of pure luck, the operators' tenacious problem solving and strive for a stable smoothly running production identified and temporarily solved a central regulation problem that the regulation project had not itself been able to.

What we can learn from this event is that no matter how we displace certainty and agency, we will also displace ignorance and dependence and thus its associated risks. The question that this gives rise to is not so much whether this new ignorance and dependence can be avoided, but rather how we can prepare ourselves for the unexpected effects that will follow. New technological endeavours may very well succeed in displacing ignorance and power, but in order to do so, they will need to establish new relations both between non-human and human actors. With these new relations new dependences and risks will also necessarily follow. In the case of the regulation project we can see the new regulation technology to distribute the new regulation knowledge into production effects. But in order to make this a technical accomplishment, the project also introduced a range of new dependences that produced new vulnerability. While the original intend was to diminish the human operators' influence on the production, the example with the sensitive temperature sensor ironically showed that the success of the project in fact still came to rely on the very same operators who's influence the project was trying to diminish.

While we can continue to displace ignorance to less critical areas, the way we grant agency to new knowledge will inevitably produce new unknown-unknowns. In the case of the operators, their persistence to keep the production going showed both at first to be a problem for the realisation of the new regulation scheme, but unexpectedly also to be what eventually enabled the regulation technology to function under the harsh conditions of the production. The operators' local and tacit know how was what the regulation project set out to circumvent, but instead it became an important part of how the project came to realise the regulation technology into the intended production effects. This illustrates how new technology through the displacement of knowledge and power, ultimately still turns out to rely on the very actors it sat out to make weaker. From this we should take with us that although the intention may have been to remove certain actors from specific types of influence, the notion of displacement rather tells us that their knowledge, power, and responsibilities are never entirely *removed* but rather *moved* from one area to another and thus better perceived as changed in character. "We can get rid of nothing and no one" Latour (2005). In this line of thinking, when technology takes over more tasks from humans, we should expect new tasks to form as a consequence of how the technology achieves to displace that agency. While we may not be able to foresee exactly what those new tasks will entail, we should expect that both human and non-human entities are affected, and thus come to play distinct roles in how the wider displacements that surrounds the technology conveys into effects.

***Internal* and *External (In)*Stability – The Role of Technological Change**

However important, the thermo sensor implementation was not the only instability that the regulation project had brought to the factory in order to stabilise its production. If we look the full range of entities that the regulation project's implementation of adaptive regulators relied on, we can see them all to entail different degrees of stability and instability. As just demonstrated by the thermo screw regulator's dependence on the thermo sensor, each entity and the connections between them could potentially cause the new regulation setup itself to become instable and malfunction. Each element that formed an operational part of the regulation setup was therefore associated with some kind of risk. In order to map how the project had displaced the factory's production from one configuration of risk to another through the new regulation solutions we will now take a closer look at the change in nature of the stabilities and instabilities at the factory.

Starting with one extreme, we can see the theoretical physics that was deployed in the representative models as stabilised through decades of scientific knowledge accumulation. Being accumulated and tested scientific knowledge, practically nothing imaginable could happen at the factory that would destabilise the theoretical physics. It was this great stability that the theoretical physicists wanted to project onto the factory's machines through their representative modelling, in order to provide machine behaviour predictions for the regulation models. The intention with the regulators can thus be seen as a displacing stability from theoretical physics onto the particular machine processes, by providing accurate predictions for the generation of error signals in the control loops. While the integration of on-line machine behaviour prediction in the regulators' control loops should enable them to enhance process stability, their ability to do so relied on all the connections that operationalized the physical explanations in their particular implementations. We have previously been through the epistemic dimension of this process when we discussed how theory was applied to the machinery through the modelling's continually displacement of uncertainties from general ignorance about the machines onto increasingly technical aspects such as energy preservation deviations and data based model verification. While the process of enhancing the models' credibility by trying to stabilise them as physical explanations of machine processes through displacing uncertainty from what was considered more critical onto less critical areas, could have been never-ending, the stability we are interested in now is however of an operational kind. This operationalization of the physical explanations at the factory bears a strong resemblance with the perspective proposed in *The Pasteurization of France*, where Latour (1993) proposes that the process that made the microbe a fact entailed a mobilisation of a vast network stretching far beyond the laboratory that generated societal effects from the fact. Thus by demonstrating the fact's worth these effects must therefore be seen as inseparable from the establishment of the fact itself. Seen in a pragmatic performative perspective, an explanation holds true as long as it is demonstrated by the performance of its machination.

In this view, what we have already witnessed from the case of the thermo sensor is that the operational reality of the regulation models' performances entailed much more evident obstacles than the representational accuracy of theoretical physics. If we set aside the instable temperature sensor we can also see other important aspects that the regulation models' integration depended on. First of all, were their software encoding and its compatibility with the existing PLC hardware at the factory. While the regulation models were encoded to fit the exact hardware that existed when the project initiated, the on going automation of the factory updated their PLC hardware during the project. By changing from an older PLC to a newer type brought not only new technical features, but also slight changes to their software- and blog-coding formats and thus their compatibility with the implementation of the regulation models. This change from the "outside" can be seen as a displacement of stability of one situation, where compatibility had been ensured by tailoring the codification of the regulation models to the existing PLC type, into another situation, where this compatibility was destabilised through the introduction of new PLCs. This *externally* emerging change to the operational conditions at the factory prevented the affected regulators from controlling the connected machinery as intended. Similarly to the blocked connection between the thermo sensor and the hot run off liquid, the incompatibility between the new hardware and the existing software form of the regulation model prevented the model from steering its connected equipment as intended. This was however mended by re-programming the regulation models to fit the new PLCs, but nevertheless caused malfunctioning regulation until it was fixed. Besides raising the point again; that technology's vulnerability emanates from its dependence on appropriate operational conditions, the case of the PLC upgrade-issues also points to another aspect of technological reliance –namely the role of the ever-changing surrounding technological environment and its often limited backwards compatibility. The surrounding technological development cause not only new possibilities, but also a continual dependence on maintenance – for example by updating and assuring compatibility with novel standards. In this perspective, we can see the inclusion of regulation technology and its new technical potentials, to be inevitably linked to a risk generated by uncontrollable external factors –such as the continual technological development as we saw with the PLC-issues.

The efficiency of technology in this regulation project can thus be understood to be entangled with, and constituted by, at least two different kinds of operational instabilities – one that related to the maintenance of *internal* connections, which in this case enabled the models to monitor and steer the machines – while the other operational instability was linked to *external* factors such as changing technological standards and their limited backwards compatibility. Changes in either the internal or the external connections can potentially displace a technological implementation from appropriate operational conditions onto non-operational conditions. That could as we have witnessed either be through a change of *internal* conditions such as the connection between the temperature of the run off liquid and the regulation model, or through *external* conditions such as the change in software compatibility that followed the introduction of a new PLC. So while technology is society made durable (Latour, 1991), it appears also, in the case of the regulation project, that this durability is closely tied to an increased dependence on the dynamics of the rest of society – through continually advancing standards and their retreating backwards compatibility.

When taking the agency of technology into account we can see it to form a paradox to the regulation project. On one hand, information technological standards and hardware forms enabled the circulation between the factory, the representative physical modellers, the regulation developers, and back again to the factory. But on the other hand, the continual progress of technological development also continually jeopardised the whole enterprise through its progressing backwards incompatibility. In order for the model developers to stay connected with the regulation developers, they needed to share not only the re-presentative *content* of their work but also mutual forms and standards to maintain the *context* of their exchange (Carlile, 2002). An example of such a context for transfer of content, between factory and modellers, was the Excel worksheets that contained large quantities of numerical production-data by re-presenting it in a software based matrix form of columns and rows. Besides the obvious need for both parties to have compatible versions of the Excel software at their disposal, this data-transfer also relied ability of the factory's automation crew to extract and transform that data-content from the production and into the Excel worksheet form as well as the ability of the modellers to transform that data from Excel and into their MATLAB software that contained the model. This compatibility of contexts may seem trivial but was however imperative for the inscriptions of the production processes to travel from the operational context of the factory to the representative physical context of the modellers. The same of course applied to the exchange between the regulation developers and the automation implementers at the factory. For a regulation model to generate effects in its target environment, both the model and its new environment needed to be carefully aligned in order to achieve operational compatibility. While these translational exchanges have all been well documented previously in this thesis, the few situations we have encountered where these technological standards had to be re-negotiated, such as the PLC re-implementation, points to the strong influence of the *external* technological environment. In comparison to the industrial mammoths that drive contemporary software and hardware development, the regulation project was just one insignificantly small enterprise that had little other choice than to comply with new emerging standards. In this view we need to recognise that what had been made possible at the factory through technology was inseparable from the instability inherent to advancing software standards and hardware forms that drive technological change. While this external progress continually generated new technological possibilities it also constantly placed the factory's operational reality at risk.

Drawing together the displacement effects of the regulation project

In this discussion chapter we have treated how the regulation project changed various aspects of the factory. We have discussed how the regulation project produced new knowledge about the production, how that knowledge granted the central management more power by displacing agency away from the operators and onto new automated regulation technology, and how that new technology displaced the production's dependences and risks onto new and unknown areas. The question that this summative paragraph will treat is what have we then learned about the regulation project's performative change of the factory's reality from tracing the three displacement aspects of knowledge, power, and risk? In what ways have we become more knowledgable about the particular event of the regulation project and in what ways have this particular case shown us something new about its interrelated dynamics of knowledge, power, and risk? I will attempt to answer these questions by first summarising what we have learned from discussing this special empirical setup in terms of the relation between knowledge, action, and risk.

Relating Knowledge, Action, and Risk

On the perspective of knowledge we took part of the regulation project's entrance to the factory. We saw how the project through extraction of production data and the operators' experiences together with new experimentally derived production data, reduced the productions' complexities to a process description report. This new re-presentation of the entire production, from its raw product reception to its milling and packing of output product, provided the regulation project with a new overview on the production. This overview enabled the regulation project to produce calculations on energy consumptions and material flows in the entire production that they did not have prior to the regulation project. We can thus see the process analyses to have displaced the production from one state of ignorance to anther state of new enhanced re-presentational certainty with the performative gain of forming a more solid basis for deciding which machines to start developing regulators for. While displacing existing known-unknowns about the transversal process dependences into new known-knowns, the process analysis also generated new known-unknows that emerged as new questions about the internal processes of the machines. While the new knowledge and certainty that the regulation project produced can easily be found incomplete in a representationalist view – because it will never become a perfectly complete and accurate mirror-like representation of the world, it must instead be recognised for its usefulness to displace power as it became means for coordination of new action. What this leads to is that we in a non-representationalist view on knowledge (Knuuttila & Voutilainen, 2003) where we can look for meaning and value in the project's epistemic process by how it displaced the one situation into new possibilities to act. The question of certainty can instead become a pragmatic question of agency.

However in order to convert their newly attained analytical insight into production gains, the regulation project had to not only affect its own agency, but also displace that of the operators who were in charge of the practical operation of the production onto new regulation technology that was believed to be more controllable. However the regulation project's intended improvements of the production did not easily realise without introducing other problematical issues at the factory. First of all the centralised power of the new regulators only worked when within proper operational conditions. This meant a displacement of dependence, not entirely away from the operators, as intended, but onto the maintenance of the technical apparatus that supported the regulators, and thus again back onto the operators who were responsible for this practical maintenance. Instead of ridding the production from its dependence on human operators, the regulation project displaced their responsibilities and practical work tasks onto maintenance of this new part of the factory's production machinery. Another issue that related to this increased reliance on the working conditions of the new regulation technology was its dependence on the external environment through its changing technological standards.

In order to draw together what we have learned from the regulation project's displacement of epistemic effects, agency and power, as well as dependence and risks, I have summarised the major characteristic effects into table 8.2. Table 8.2 compares the situation before the regulation project to that after in terms of the types of displacement effects we have extensively discussed throughout this chapter. By boiling down the regulation project into its major effect we can better juxtapose them as inseparable elements of the same combined displacement from the old state of the production to the new regulated state. It is therefore important to read the columns as different characteristics of the same situation. The intention is thereby that we can easier trace the connections from say the dependences and risks in the old setup to the epistemic effects of the new setup, by seeing them as means intended to discover new solutions the old problems. Any characteristic feature of one column is thereby somehow directly or indirectly connected to any characteristic feature in the other column. Consequently, we can thereby see the organisational problem associated to the operators' subdomain interpretation of the factory's production to be directly related to the centralisation of agency and power by means of the new regulation technology as the intended solution. Indirectly we can thus seen the subdomain knowledge to also relate to the new internal and external unintended dependences and risks that came along with the new regulation technology.

Displacements:	Before regulation project:	After regulation project:
Epistemic	Tacit Subdomain Operational knowing how	Data- & simulation based Trans-domain & Submachine Optimisation knowing that
Agency & Power	Decentralised by operators and subdomains	Centralised through adaptive regulators
Dependence & Risk	Operators' idiosyncrasies & sub-optimisation	Regulators' operational conditions: Sensors (internal) & Technological compatibility (external) Operators' new knowing how External technical consultants

Figure 8.2: Table of displacement effects comparing the factory's situation before the regulation project with that after. Illustration by Author, 2013.

We can thereby see table 8.2 as an illustration of the boiled down total comprehension of the regulation projects' displacement of the factory from one state to another. The picture we hereby get of the pre-regulation production setup is dominated by problems that all are somehow related to the old organisations reliance on the human operators and their particular ways of doing things. We thereby see agency and power in the production to be primarily allocated with the human operators who ran the production by means of their tacit subdomain know how. The risks were therefore placed on the operators and their idiosyncrasies about the best way to do things, which typically meant less than ideal transversal production effects. What seemed optimal from one operator's view, from what he could see and knew of his subdomain, often caused problems in the following subdomain. We can thereby see the whole process analysis to generate a radically new interpretation than that of the operators. Where the operators had focused on smooth and what they saw as problem free operation, the regulation project introduced an idea of optimisation. Transversal process effects were analysed and compared to simulations of the machines hidden inner workings in order to produce a vision of an optimal production that, if correctly setup, could ensure optimal production yields with minimal energy consumption. The technological machination of this radical new insight to the production were thereby an attempt to circumvent the idiosyncrasies of the operators and ensure an optimal production that was less dependent on the human operators by taking over critical parts of their agency. This vision, however appealing to the central management, did not out-fold onto realisation in the production without certain complications. First of all, as any machination, the new regulation showed to depend on the operational conditions just as well as the production machinery it was designed to stabilise. Parts that had been unproblematic in the old production setup suddenly refused their enrolment in the machination scheme of the new regulation. We witnessed the thermo sensor as an example of how vulnerable the new setup apparently had become. While intending to replace old liabilities in terms of the human operators in the original production setup, the regulation project thereby introduced new risks. These were not only unintended, but also unexpected and as I will get to in the following paragraph especially problematical because the organisation came generally unprepared to face these new risks.

Organisational Displacement Knowledge, Agency, Risks, and *"Relative Distance"*

Another way to illustrate the displacement effects of the regulation project is to analyse them according to the factory's organisational setup. In figure 8.3 we see how the displacements effects generated by the regulation project were distributed according their "organisational distance" to the factory's central management. Organisational distance is in this context relative to the central management's control. Distance indicates therefore the degree of control that the central management's has over something and is thereby not directly related to physical distance. Two operators can for instance sit next to each other, but if they do not coordinate their actions, they can be at great "organisational distance". By making the organisational association the constant we can thereby better see how the different layers of the organisation were affected by the regulation project. At the same time we can also learn something about the nature of the displacement effects by seeing their variation across the different organisational layers as illustrative of their "organisational tendencies". The distinction of organisational layers is organised so that the management segment is denoted to the "central" layer. What the management can be seen to directly control is placed in this layer notwithstanding its physical placement. The "peripheral" layer refers to factors and actors that are within the organisational setup but are only under limited controlled by the central management. Movement between the peripheral and the central layer thereby denotes a significant change in the central management's effective control. The last layer consists of factors and actors who are "external" to the organisation and thereby completely outside the organisation's control. While this layer contains external contractors who are hired to do things for the organisation that were otherwise outside its reach, the point with placing them in this layer is that the reason for hiring them in the first place, signifies important external factors to cause the need for their services.

Displacements: Organisational control layers:	Before regulation project:	After regulation project:
Central	Limited management controlled production	Agency & Power through adaptive regulators Transversal process optimisation
Peripheral	Operators' uncontrollable subdomain agency	Regulators' operational reliance on sensors (internal Risk) Operators' new knowing how
External	Raw product variation	Technological compatibility (external Risk) External technical consultants

Figure 8.3: Table of displacement effects comparing the factory's situation before the regulation project with that after in relation to central, peripheral and external displacement effects. Illustration by Author, 2013.

By moving from the first row and downwards in the factory's pre-regulation setup, we can see the characteristic features of an organisation, as we discussed above, which production primarily relied on how its human operators ran its production. From the centre of the organisation, the management had limited means to control the agency of the operators who ran their separate production sub-domains with little focus on the transversal effects of their actions. Another major problem to the pre-regulated setup was the variation of incoming raw product. Variations in the raw product meant that the production's operation and output relied on how these uncontrollable variations were handled in the different subdomains and by the operators who were in charge. We can thus understand the pre-regulated production as compromised by a decentralised and relatively uncoordinated agency that was further challenged by uncontrollable external variations in raw product quality. When we move to the situation after the regulation project, we see how it has caused different changes in all the layers of the new organisation of the factory. Foremost, the fundamental and intended effect of the regulation project was displacement of the human operators' uncontrollable subdomain agency with that of the new centrally controllable regulation technology. While the central management thereby gained a more direct control over the transversal production processes that they did not have in the previous setup, this change also brought other untended effects in terms of new dependences and risks. The important point that is illustrated in the above figure is that while the central management achieved a more direct machinated control over the production, they also came to depend on this technology's new operational conditions. Because the maintenance of these conditions were still largely unknown to the operators, we can see the new regulators to generate new risks that were even more peripheral than the operators whom they tried to replace. Additionally, the operation of these regulators thereby came to depend on the very operators whom they were to replace because they now had to develop new know how about the maintenance of this new technology. The displacement effect tendency is thereby that in order for the regulation project to centralise control through technological means, the same means generated new risks that instead became more peripheral than those they were designed to replace. The most extreme example of this peripheral displacement of risk-effects was the added reliance on external technical consultants as well as the increased dependence on changes in the surrounding technological environment. Another recognition that we can draw from this tendency is that the regulation project thereby can be seen to intentionally displace epistemic effects such as the new understanding of the production process together with agency and power by means of the new regulation technology towards the central management, while by the same means unintentionally displacing dependence and risk further away from the central management. We can see this split between the epistemic effects and the new risks as a potential problem because its peripheral allocation of new dependences and risks were not accompanied by epistemic initiatives that prepared the organisation to handle what these dependences and risks could translate into. Figure 8.4 illustrates this organisational split effect of the regulation project by visualising how the distribution of responsibilities in the organisation was displaced by the implantation of the new regulation technology. The left structure signifies the organisation with is distribution of responsibilities between the management (blue), the human operators (green), and the automatized information infrastructure (grey) that had been implemented during the automation of the factory. The yellow oval signifies how the adaptive regulation technology displaced agency by being keeled in between the domain of the human operators and the automatized information infrastructure. We can thereby see the new regulators to take over tasks that before were distributed between the human operators and the previous automation system. These tasks were for instance the aforementioned adjustment of set values that they took over from the human operators and the online machine steering, which the new regulators took over from the existing automation.

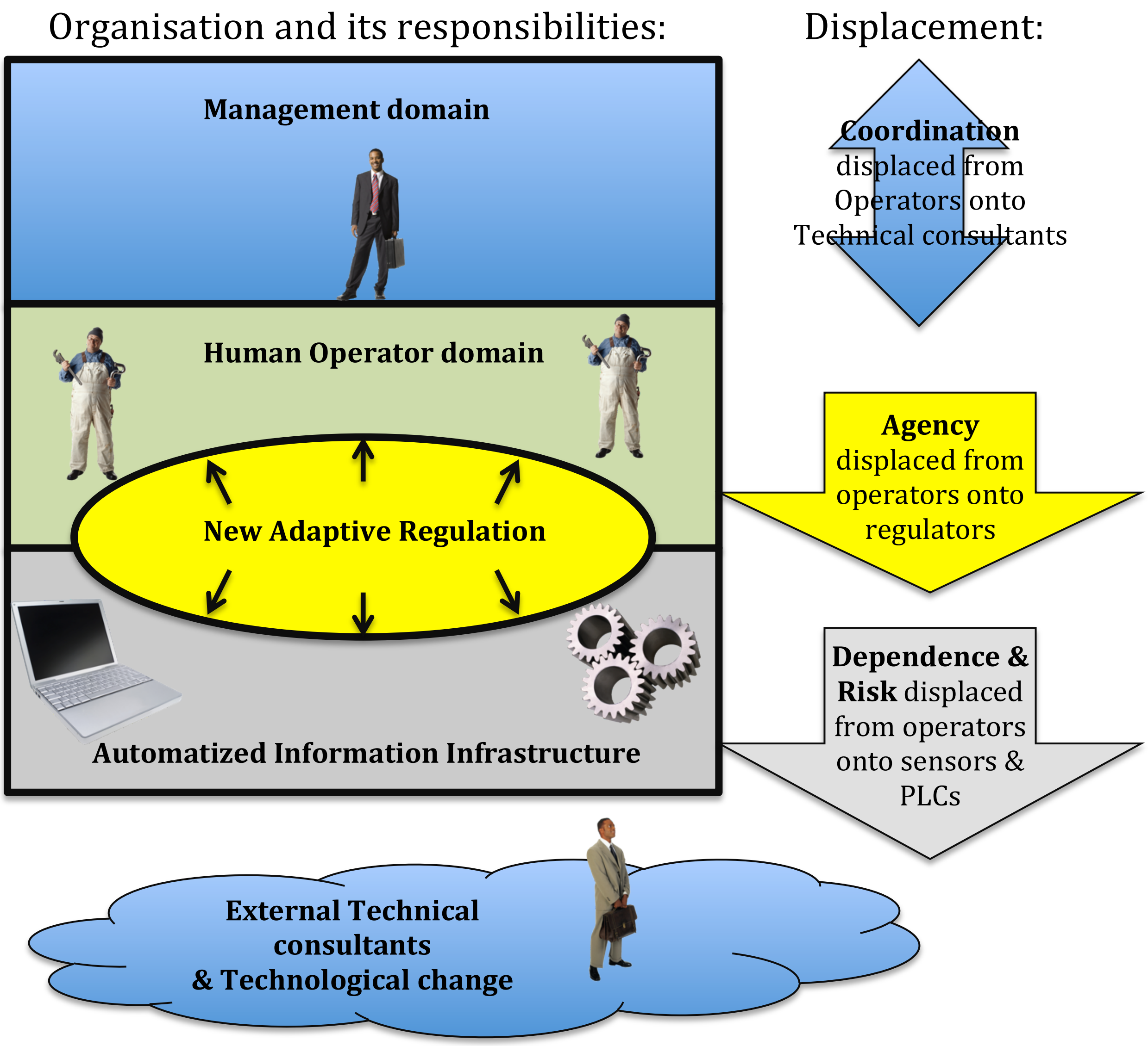


Figure 8.4: Illustration of the various displacement effects in the factory's organisational structure. Blue signifies the management level. Green signifies the human operator level. Grey signifies the automatized information infrastructure. Yellow signifies the new adaptive regulation technology. The blue cloud is textra-organisational. Arrows to the right signifies the various displacement effects . Illustration by Author, 2013.

The arrows to the right illustrate the important displacement effects that we can see the regulation technology to have generated. From the top, we see the blue double arrow that illustrates how the management's coordination of work changed in character by exchanging the troublesome coordination with the human operators onto external technical consultants in order to set up the new regulation technology. This manoeuvre could be seen as part of the "back door" approach to change the operational conditions of the production through technology instead of a direct "front door" confrontation with the human operators. The yellow middle arrow indicates the intended effect of this conflict-avoiding technological manoeuvre in terms of the displacement of the human operators' agency onto the new regulators. Continuing the yellow arrow, we find the grey arrow that signifies the resulting unintended displacement effects of the mathematisation of the production. This arrow shows how the new dependence and risks are pushed further away from the central management and into the peripheral layers of the organisation as well as onto external factors such as the surrounding technological progress. We can thereby see this process as a reversion of the original intentions with the regulation project by reemphasising the role of the human operators while also introducing additional human actors in terms of the new reliance on technical consultants. Instead of liberating the production's operation from human influence, we rather see the regulation project to displace the human role from one set of responsibilities onto another set. Paradoxically, the new regulation technology can be seen to exchange one task, that was seen to be too challenging for the human operators, with another task, that entailed maintenance of the new regulation, for which there existed yet no experience nor any formally organised initiatives to encounter.

Chapter Nine

Theoretical Lessons From the Regulation Project

Reflections on the Simulation Modelling Literature

In the literature review on simulation models found in the introductory section of this thesis I identified two major axes of discussion. One axis centres on the epistemological question concerning what kind of theory of knowledge that best suits simulation modelling. This discussion also relates to the fundamental ontological question concerning how we understand what simulation models are. Does models belong to theory or do they belong to experiment? Besides this directly extended historical interest of the philosophical discipline, the other axis of discussion has a somewhat more pragmatic interest in the distinction between models truthfulness and their usefulness. We thus have on one hand the classical epistemological discussion centred on the theory-experiment split, where we on the other hand have the more pragmatic usefulness-truthfulness discussion. While these two axes of discussion indeed often are intertwined, the point that I want to pursue at this point in this thesis' discussion is that truth-value, and in that regard the epistemological discussion as such, is only one out of many types of usefulness that are relevant to consider when treating the subject of simulation models. My argument is more precisely that usefulness of models must be understood to depend on the particular contexts of their usages. For instance, if we consider a scientific context, the truth-value and credibility of a simulation model may be paramount for the model's usefulness. However, it might not necessarily articulate the more central and maybe very practical reasons for using a particular model in the first place or the most significant gains its usage can be seen to lead to. Furthermore, if we look at simulation models outside the context of science, their actual usefulness may have very little to do with whether they are considered truthful or not. This leads us to the core question of this discussion – through what kind of context perception(s) can we better grasp the particular usefulness of the various kinds of models in the regulation project? From the previous discussion in this thesis, we have seen that the various identifiable effects that can be related to the use of models in the regulation project, definitely extends far beyond the very objects these model have been designed to re-present. In essence, model-effects in the regulation project extend as far as the project itself – which we have seen to interrelate a greater variety of performative aspects such as epistemological-, power and agency-, organisational-, and risks- issues. A central purpose of this discussion is therefore to approach what kind of context that offers us an useful analytical point of reference that enables us to better understand the dynamics of the regulation project and its use of different model variations. In order to establish a safe footing for this search i.e. a more appropriate context definition for the regulation project's modelling, we will build on the indications that are offered by the existing literature on simulation models.

From Philosophy of Science onto a Co-productionist Perspective on Models

From the philosophical takes on simulation modelling we have been presented with an epistemological depiction of simulation models as occupying an unruly space between data and theory (Sismondo, 1999). This picture can be seen as a direct result of the historical experiment-theory split within philosophy of science (Rohrlich, 1990; Winsberg, 2003). The experiment-theory split can furthermore be seen to project its bifurcated view onto the current interpretations of what simulation modelling is by forming two camps; one in support of simulation models seen as belonging to theorising (Dowling, 1999), and another that argues for simulation modelling as belonging to experimentation (Humphreys, 2004).

The philosophical split:

Experiment ← // → **Theory**

? (mathematical) **Models** ?

More recently a third position has however emerged that sees simulation models as intermediates or hybrids between theory and experiment. This third position has gained increasing support within STS (Johnson, 2006) and offers an interpretation of simulation modelling that seems more applicable to the mathematical modelling we have observed in the regulation project. By means of its more pragmatic position on the experiment-theory split it enables us to better recognise the theoretical physicists' mediations between theoretically- and empirically derived re-presentations in their model construction.

The three positions on simulation models:

(1) **Experimentation** (2) **Theorising**

(3) **Intermediate/hybrid**

While this third position opens for a looser interpretation of what simulation models can do, it nonetheless also has its limitations when taking into account the full range of effects that we have observed modelling to generate in the regulation project. These effects, such as the displacement of agency and risk onto new entities and new areas, extend well beyond what can be recognised as experimentalism, theorising, or any intermediate combination of the two. In order to make more meaningful interpretations of the roles that modelling and models have played in the regulation project, we therefore need to extend or view beyond the epistemological categories such experimentalism and theorising. We might then ask why the existing interpretations of simulation models seem inadequate to account for the modelling in the regulation project? A probable reason for this inadequacy can be seen if we look at the kind of contexts in which simulation modelling predominantly has been studied. Previous work has primarily treated simulation modelling as elements in scientific endeavours or at least as elements in practices that have their methodological roots and credentials from science. The regulation project and its modelling activities cannot be meaningfully appreciated as a whole, if seen in the restricted view of a scientific context.

Part of my argument is that we can learn something new and interesting about simulation modelling, from the regulation project, by outlining a more appropriate context for its interpretation that deviates from that restricted to science. This is however not to say that there is no valid ground for comparison nor that the regulation project has nothing to do with science. The theoretical physicists' work in the regulation project had for example a lot to do with science. Nonetheless it had also a lot to do with the development of new energy-efficient regulation solutions for the process industry, which is beyond our typical conception of *scientific work*. While the physicists used their representative models and simulated results in conference papers and articles for scientific peers, they also used the exact same models for machine behaviour predictions. The models became in this way also means for the development of regulation technology and thus part of practical solutions to contemporary societal problems. We can thus see the regulation project as a case of mathematical modelling that has been used as means for connecting knowledge problems in a of scientific context with practical problems in an industrial context. The modelling in the regulation project thereby connected a variety of problems that related to, but were not restricted by, a scientific context.

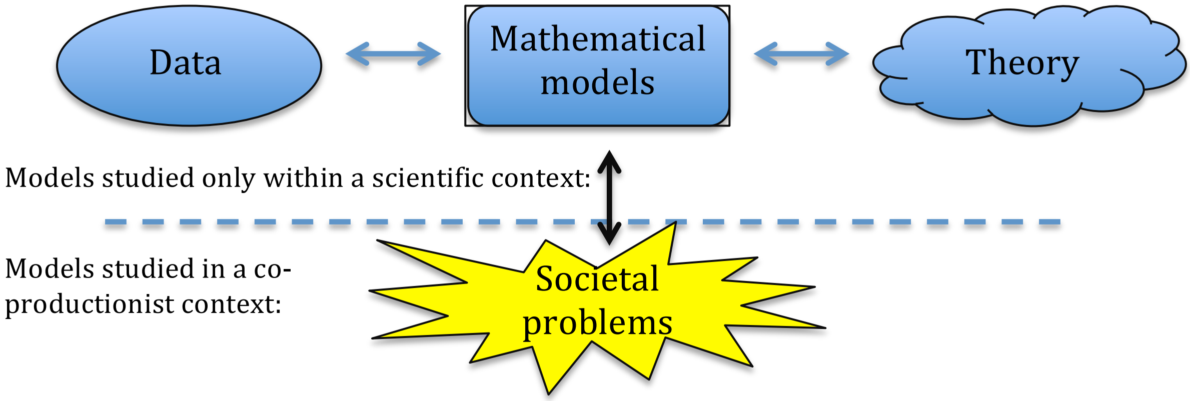


Figure 9.1: Illustration comparing simulation studies limited to scientific contexts to a simulation study that encompass scientific- and other societal contexts. Illustration by Author 2013.

As illustrated in figure 9.1, my study thereby places modelling into a context that stretches beyond that of science and encompasses societal challenges such as contemporary process industry's energy-efficiency, its competitiveness as well as its very existence in the future. In this perspective the regulation case serves as an example of how models function not only as mediators between data and theory, but also between data, theory, *and* practical problems such as how we can predict and improve steering of industrial process equipment. What this view offers to the existing presentations of simulation modelling is a deviation from the predominant focus on science- and the meta-physically driven categorisations of experiment and theory, by placing simulation models into a context that extends beyond that of knowledge generation. This new context thus has to include the different material and technological settings, in which the various states of models have produced effects during the regulation project. It thus has to stretch across the entire regulation project in order to connect the particular machines with the theoretical physics that was used to model them. Only in this co-productionist view (Jasanoff, 1996) is it possible to trace, and make sense of, how the various states of models and other re-presentations form an unbroken chain of transfer between the machine processes at the factory and theoretical physics. If we carefully examine what qualities that have been lost in order to gain others, across the chain of translations that connected the different states of models, we should be able to identify what is special about the context of the regulation project. –And thus learn something new about modelling in that specific context. We will therefore take a closer look at the different ways in which the regulation project has used models in order to get a better idea of how these relate to, and deviate from, what we know from the literature on simulation models.

Model Applications - Epistemic and Technical dimensions of Modelling

We can see the regulation project to deploy modelling in two radically different ways. One was as an extension of the process analysis, where the construction of representative mathematical models provided new knowledge about the internal machine processes, while the other was about operationalizing that knowledge in the factory's production. We can thus see modelling as means for two different, however intertwined, performative ends in the regulation project –the production of new knowledge and energy-efficient optimisation of industrial production. The project's application of models began as means for knowledge production. As part of the overarching epistemological process the models were used to produce specific pieces to fit the greater puzzle of the how the entire production operated and interdepended on various sub-processes and their parameters. In the perspective of displacement effects, we recognised that the models' epistemic function was to displace certainty in theoretical physics onto the inner workings of the machines by which the ignorance about these internal machine processes simultaneously was displaced onto how they were made to connect with theoretical physics. We can thereby see this kind usage of models to fit Rheinberger's (1992) definition of *epistemic things,* which he designates to the smallest functional units of an experimental system that are under investigation (Rheinberger, 1997). Epistemic things are according to Rheinberger "open, question-generating, and complex" and have a complexity that increases under academic analysis rather than decreases or reduces. Rheinberger distinguishes between the epistemic *content* and what he sees as the well-understood and stabilised context of the investigation, which is made of what he calls *technological objects*. Rheinberger sees technological objects as the functioning parts of an experimental setup that behaves according to known regularities and thus form what he calls "answering machines". The distinction between epistemic things and technological objects thereby illustrates a dynamical relationship in experimental science through how it displaces its content of investigation by slowly stabilising it over periods of time –whereby it becomes the new context for investigation in which new epistemic things emerge as the new content. Epistemic things thereby become stabilised well-known technological objects that in turn create the conditions for the emergence of new epistemic things. In relation to this perspective we can likewise see the knowledge production of the regulation project to be propelled by its continual displacement of known-unknowns (epistemic things) into known-knowns (technical objects) that thereby formed the conditions for the emergence of new known-unknowns. When mentioning Rheinberger's conception of epistemic things and technological objects, it is also necessary to include Knorr-Cetina's (1997) critique of Rheinberger's interpretation of experimental systems. While Knorr-Cetina adopts Rheinberger's dichotomised interpretation, she finds his equation of technological objects with instruments problematical. With reference to computer hardware and software, knorr-Cetina argues that such technologies can both be "present (ready-to-used) and absent (subject to further research)." Knorr-Cetina's point can be seen to displace the differentiating line between instruments that she sees as "tools" that are "available-means-to-an-end within a logic of instrumental action" and terms *technical things* and "technologies, which are simultaneously things-to-be-used and things-in-a-process-of-transformation" (p.10). The later category Knorr-Cetina terms *epistemic objects* (Knorr-Cetina, 2001). While Knorr-Cetina's and Rheinberger's different interpretations can be seen to accentuate different epistemological dynamics; Rheinberger underscores how things and objects exchange places through the progress of experimental science, whereas Knorr-Cetina instead emphasises objects' unfolding ontology and lack of completeness, -I instead want to synthesise both interpretations in order to better define what makes the epistemic dynamics of the regulation project special and interesting.

Merz (1999) and Sundberg (2009) adopted the distinction between epistemic things and technical objects onto the specific discussion on simulation models. In her study of a special kind of simulation models called event generators, Merz deploys both Rheinberger's and Knorr-Cetina's distinctions in order to clarify how different use contexts within particle physics can configure the same event generators as epistemic things and technical things in different ways. Merz termed these event generators "muliplex" due to their multiple meanings according to their different uses. Sundberg (2006) on the other hand, expanded Knorr-Cetinas's framework beyond scientific practice through her analysis of meteorology where she illustrated how atmospheric models can be seen to emerge as epistemic objects before they become stabilised into operational forecasting models and thus transforms into technical things. The principle in Sundberg's depiction of how scientific models stabilise and become operational outside the context of science somewhat resonates with the two distinct ways we have seen models to be used in the regulation project. However while we in the regulation project can recognise the principle behind the process by which mathematical models were translated from epistemic things into technical and operational things, the similarities only holds to a certain point. While Sundberg described how the differences between the operational- and the scientific context entailed different demands to their operational uses of the models, the regulation project revealed more than different operational demands. The regulation project also illustrates how the regulation models, through displacement effects, transformed the very environments in which they were operationalized. From the preceding discussion we saw that the meaning and value of the new knowledge was as new means for displacing agency and power onto actors in the production. In this sense we can see that the use of representative models provided new means for action. The epistemic value of these models was thus not restricted to their scientific origin. We witnessed for instance how the operational demands of the new regulation models required new 'know how' about the maintenance of their operational conditions and thus linked new epistemic processes to their technical application in the production. We can thus see that although the intended performance of the new regulation models was purely technical, their actual operation still relied on new epistemic processes to happen in order to operationalize the models in the production environment. This recognition somewhat blurs the analytical distinction between epistemic- and technical things in the case of the regulation models because they did not as much become stabilised means for the surrounding production as an instable *epistemic* end, as much as they became an inseparable operational part of that entire production unit. In an operational sense we can thereby see that the implementation of the regulation models entailed an epistemic process that came to concern the operational alignment between the regulation models and their new operational environments. While Merz (1999) points to that the same event generators served different epistemic goals, and thereby illustrated how the distinction between technical use and epistemic use varied from context to context, we can recognise a similar dynamic to take place in the regulation project. However what seems to be interesting in the case of the regulation project is how we can see the implementation of the regulation models into the production, to displace what made up the content and the context of investigation as the project developed. To clarify this distinction the following paragraph will focus on how we can use the distinction between the stable and thus technical entities and the instable and thereby epistemic entities in order to spell out the context-content dynamics of the regulation project's use of models.

From an analytical perspective, we may maintain that we can identify an overarching epistemic use of models that translated the factory into knowledge artefacts, as well as another overarching technical use of models that materialised those knowledge artefacts back into production yields. However from an empirical point of view, the project had so many crossovers between its various states of models in these two opposite *epistemic* and *technical* processes, that it is difficult to distinguishing between its pure epistemic- and pure technical uses of models, if not only an analytically constructed reality. My point is that we can see all states of models in both processes as simultaneously technical and epistemic things: –Technical, because all states of models formed stabilised parts of an operational system that produced conditions for other entities to be stabilised. However we can also see the models as epistemic, because their operational entanglement continued to surprise by unfolding into increasingly more complex assemblages that had to be reconsidered and reconfigured. Seen from this perspective, the regulation project rather supports that it was the various ways in which the different models were epistemic and technical that we should see as the interesting variables. The special about the regulation project's models was in this view how their epistemic and technical values changed along with their transformations from one shape and one application to another. The representative models could thereby be seen as one extreme. As technical objects the representative models operationalized known and stable physics onto the machines, while as epistemic things, their configuration of physical theories had not yet been stabilised into the final model –and thus made the models themselves into known-unknowns. At the other extreme, we can see that the configuration of physical theories had stabilised and integrated into technical configurations that were part of the of the regulation

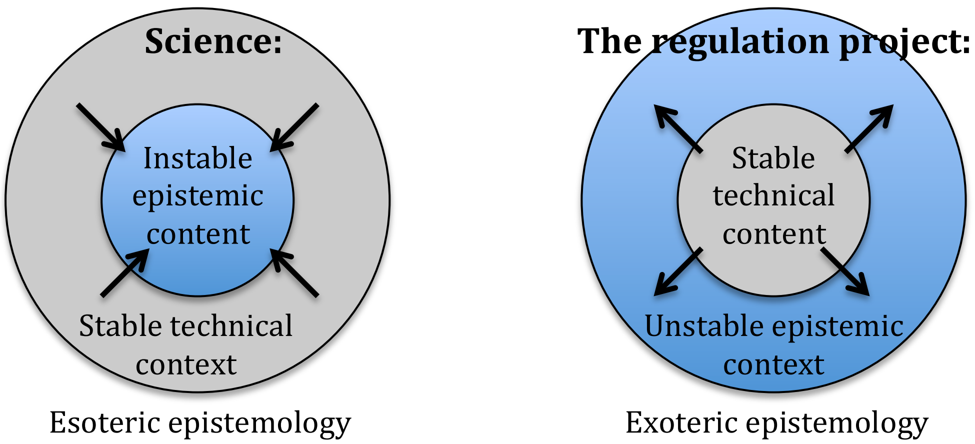


Figure 9.2: Illustration comparing the classical conception of what I call esoteric science (Left side) to my conception of the "exoteric" epistemology of the regulation project (right side). Illustration by Author 2013.

models' operational core. The epistemologically interesting about these technical regulation models was not about their underlying theoretical structure. Instead the epistemologically interesting came to concern how their particular machine implementations could be enabled to produce the intended effects. On these conditions we can also recognise the principle in epistemic things stabilising into technical objects to apply to the regulation project. However, contrary to Rheinberger's depiction of experimental science, the regulation project used theory as the stable basis consisting of *technical objects* and worked from that onto the particularities of the production setup, which instead came to be what we can see as the instable *epistemic things*. The regulation project can thereby be seen as a different epistemic and technical endeavour than those we know from the scientific cases of simulation modelling. Instead of forming a *stable technical context* within which an *unstable epistemic content* could be investigated, the modelling in the regulation project rather formed a *stable technical content* that was integrated onto what became an *unstable epistemic context*.

The above figures illustrate the significant difference between Rheinberger's interpretation of the technical and epistemic setup in experimental science and the technical and epistemic setup we can recognise in the regulation project. It is important to note that this illustrative comparison not only portrays a reversal of context and content in terms of their epistemic and technical status, but more importantly, also a reversal of epistemic directions. Signified by the arrows, we can see Rheinberger's version of science to progress inwards by *in-folding* the content's openness and increasing question generating complexity by realising further esoteric sublevels of these epistemic things' infrastructures. We can also see this interpretation of the epistemological dynamics of experimental scientific practice to reflect that outlined by Knorr-Cetina (1997, 2001). By using Knorr-Cetina's own phrasings we can see the centre of the figure to contain what she terms epistemic objects with their "unfolding ontology", their "lack in completeness of being", and their "capacity to unfold indefinitely". With a slight translation of Knorr-Cetina's phrasings I hereby suggest the experimental dynamic to be more precisely characterised as esoteric and *in-folding* rather than "unfolding" as Knorr-Cetina suggests. This slight translation has the significant advantage that we can more precisely articulate the distinction between the in-folding and esoteric epistemology of experimental science and the out-folding and exoteric epistemology of the regulation project. This epistemological distinction would seem incomprehensible with Knorr-Cetina's conception of the epistemic-technical dichotomy. The ontological premise however stands, whether we compare experimental science to Rheinberger's or to Knorr-Cetina's interpretation. Experimental scientific practice can be characterised as esoteric and in-folding, by constantly seeking through its evolution to manifest additional sub-levels of its content of investigation. Another advantage of this translation is that it draws together the epistemic dynamics spelled out by Knorr-Cetina with those of Rheinberger. By deemphasising the articulation of where we exactly place the metaphysical distinction between epistemic and technical entities, we can instead focus on the major epistemic trends. Experimental scientific practice constantly epistemologically in-folds by constructing yet more complex realities "in-here", in order to realise further sublevels of the esoteric universe in which it manifests its content of investigation. The regulation project on the other hand, progressed outwards by *out-folding* its content's technical stability onto the context, which it thereby destabilised by realising further exoteric super-levels of these technical things' exostructures. When I say that the technical content *destabilised* its context, it is important to note that the regulation project intended to produce new stability in the fatory's production –the surrounding context. But in order to achieve this, the regulation project needed to destabilise the established alignment of the production by introducing the new regulation technology as technological solutions. The new stability produced in the production can thus be understood as a displacement of the distinguishing line between the still unstable elements of the production, and the re-stabilised elements that now formed part of the regulation's machination of the factory. While technological objects in Rheinberger's interpretation are seen as answering machines, we can in the regulation project also see them as question generators because their complexity out-folded as the exostructure they became part of expanded further onto additional exoteric-levels of, what in this type of enterprise can be seen as, the epistemic context. Rheinberger's classical interpretation of experimental science indicates an understanding of the epistemological process as *in-folding inwards* –deeper into the esoteric content, while the epistemological process in the regulation project instead *out-folds outwards* –onto the exoteric context. We thus have two different epistemologies; the esoteric in-folding reality within the scientific laboratory; and the exoteric out-folding onto the surrounding world.

My reason for accentuating these opposite directions is to deemphasise the distinction between entities that are considered epistemological and entities that are considered technical. What we can learn from the regulation project is that things' epistemic and technical qualities can be seen to change from one context to another, and that the interesting question rather lies in how things' technical and epistemic qualities are displaced onto new configurations through the processes we study. In this perspective we should instead focus on the major epistemological premises behind what we study. Although a process like the regulation project does not in-fold as a classical experimental science it appears to produce novel recognitions that are equally important to understand. I propose that it is by looking further into the exoteric nature of these novel recognitions that we can become more capable to comprehend how the esoteric world of science is applied onto the surrounding exoteric world – and thus how we can better grasp the case of the regulation project as an interesting example of co-production between science and the rest of society. In the experimental scientific model, the epistemologically interesting would be about what is realised by technically manipulating the content through the context. Whereas in the regulation project the epistemologically interesting was instead about what was realised by applying the technical content to manipulate its surrounding contexts.

Rheinberger's epistemic-technical dichotomy does however not offer us a useful framework for understanding how the regulation project relates to, and builds on, theory. The discussion of the role of modelling in the regulation project will therefore continue by comparing its practice to what I see, as the for the purpose, the most adequate frameworks for understanding how theoretical and empirical knowledge are made to relate in scientific contexts. These comparisons can thereby help us to specifying more exactly how the regulation project relates to, and deviates from, science and thereby what makes the regulation project's exoteric practice special and interesting.

Comparison to Models of Science

One of the most comprehensive models I know to offer a framework for comprehending how science operates by translating the world into words, and thereby considers both theory and the world as part of the same realm is Latour's (1999) concept of circulating reference. Through the concept of circulating reference we can see Latour to extend the actor-network perspective onto the central practice of science that according to Latour's description has to do with establishing and maintaining scientific reference between different re-presentations of the world. This particular network-perspective thereby creates an interesting bridge to Latour's (1987) earlier work on how scientists and engineers engage with society by folding science into technical projects. Circulating reference can thereby be seen to provide us with a framework that helps us to incorporate how we can see the modellers in the regulation project to have transformed and aligned theoretical re-presentations with empirical re-presentations. The important implication of including circulating reference is that we thereby can interpret the modellers' manipulation of both theory and the world in terms of how and with that they generate stability in their models. In other words, we can thereby in this perspective better examine what made up the stable technical basis that the modellers used to stabilise something else, which we then can see as the instable and epistemic artefacts in their practice. This insight is a very central piece of information that can help us to understand the greater puzzle of how to comprehend what is special and interesting about the context of the regulation project.

There are however important differences between the phenomena of science that Latour describes, and that of the regulation project, which we need to clarify before we can use the framework offered by circulating reference to help us building a more comprehensive understanding of the modellers' work. First of all there is the aforementioned difference between the contexts of the two phenomena. Circulating reference is about how science is performed as a descriptive practice that translates the world into words while constructing and maintaining what Latour designates as scientific reference. The regulation project however, was instead about solving operational issues in a particular production system. The regulation project can thereby be understood to deploy scientific content as *prescriptive* means for reconfiguring a particular system's performance, rather than as descriptive ends of generalised phenomena. So while circulating reference and the regulation project both can be understood to operate through cascades of translations that connect something concrete, material, and complex at one end with aggregated and abstract re-presentations at the other end, they do so for different ends, and as we have just discussed in the preceding paragraph, through what we can understand as different epistemological directions. In order to reveal other relevant performative differences, there are however additional important epistemological dissimilarities that we can use to characterise between the two contexts. According to circulating reference, science is about extending its extremes both into more particular re-presentations of what is under examination, while simultaneously extending into more aggregated re-presentations of that phenomenon. We can see this as extending a network by spreading its already connected extremes further apart, in order to make it both re-present more esoteric features of what is under study, and do so through more aggregated explanations. The performative gain by reducing what is re-presented in one extreme, into aggregated re-presentations in the other, is to *amplify* it's *meaning* by achieving compatibility with other scientific re-presentations. The important common operator that Latour identifies is that the ability to 'go back' is maintained across all steps –while preserving the *meaning* of what is re-presented. This is according to Latour the *meaning* of scientific reference and the reality of scientific 'truth value'. The regulation project significantly deviates from this characterisation because its intended performance does not necessarily depend on scientific reference, truth-value, nor on extending the reach of both its re-presentational extremes. The regulation project instead worked on the basis of existing, however not yet connected, re-presentations of the factory's production system and re-presentations of physical theories. The connection between these re-presentations had not yet been established and therefore not yet stabilised into something technical with which to generate the type of answers that was deemed useful to the regulation project. Because the regulation project did not have the means to extend esoteric data retrieval much further into the bodies of the machines, it relied on projecting what was known about their exteriors onto their unknown interiors. The means for realising this displacement of knowledge of exterior elements onto the unknown interior of the machines was through applying established and thus *stable* theoretical knowledge about the world – to fill the gaps, so to speak. We can thereby see the modellers to deploy existing tested and uncontroversial physical theory as their stable basis, which they worked to extend onto the unknown interior of the machines at the factory. Their models thus came to form a combination of *stable* physical theories, which interconnections and relation to what they were made to re-present came to be the *instable* epistemic things of their practice. While this illustrates that the modellers incorporated theory as a technical basis for stabilising certain epistemic dimensions of their models, we still need to look further into how we can understand the modellers to have chosen and connected theoretical knowledge in certain ways during the creation of their models, in order to better grasp what was special about their knowledge practice.

The modellers' representative model construction can thereby be seen as an approach that sought to produce plausible explanations about the machines' internal workings by connecting machine data with the physical theory that the modellers deemed applicable. The regulation project therefore first had to transform re-presentations of both "extremes" – the *data* and *theory*, in order to align them and make them compatible. It was exactly this initial, however very important, connecting manoeuvre that we witnessed the theoretical physicists to perform during their modelling meetings when manipulating inscriptions on their white- and black boards. Distinguishing between these inscriptions as either technical or epistemic seems straightforward impossible from an empirical point of view. The interesting questions is rather how we can understand exactly what the modellers did by displacing these inscriptions from separate places and origins and onto a combination on the same flat surface? – What had the modellers started building? Which ingredients were transformed into what product, and what performative advantages can we attribute to this creation over what its ingredients could offer? While circulating reference seems to be about producing knowledge by taking things apart, the modellers in the regulation project instead brought things together.

Building on these initial hand-sketched re-presentations that combined both inscriptions of selected aspects of the machines at the factory and selected inscriptions of physical theories, the modellers build a conceptual model that functioned as a platform onto which they could add more connections to both physical theory and the physical machine. We can thereby see the models to be conceived as intermediate re-presentations, not as much *in between* data and theory, neither belonging exclusively to either, but rather as concrete *material combinations* that consisted both of concretised re-presentations of theory and abstracted re-presentations of the machine. By growing from the middle instead of the extremes we can see the model construction to follow a fundamental operational principle of circulating reference. But instead of doing so for the sake of extending the extremes, the modelling did so for the sake of building a more comprehensive explanation of particular machines by means of existing theoretical knowledge about how we understand the world together with knowledge of the specific machine. We can thus see the modellers to construct their models as particular mathematical configurations that were made to connect theoretical knowledge *about* the world with empirical knowledge *of* the world.

From this unique, however still weak, configuration of explaining theory (the explanans) and elements to be explained from the machine (the explananda), the modellers added both more re-presentative elements to be explained and more explanative physical theories. We can thus see the modellers to expand their models by constructing yet more links from the models and out to the extremes in order to generate an explanation that more extensively could account for the complicating particularities of the physical machine. The models can thus be understood to out-fold its mathematical complexity onto both established physical theory and onto the particular machines and the factory. Where circulating reference is about extending re-presentational extremes in order to reduce and compress data gathered in one extreme into a more powerful explanation of the other extreme, by tying as many explananda to as few explanans (Latour, 1988), the physicists' representative modelling was instead about combining enough existing theoretical explanations in order to produce what they believed to become an adequate re-presentation of the particular machines' complexities. What the modellers achieved was thereby quite different from what is achieved according to circulating reference. Circulating reference is about building a strong explanation by reducing as many explananda in order to amplify as few explanans as possible. The distance, that is constructed in circulating reference between what is explained in one extreme and what is doing the explaining in the other extreme, has the performative purpose of amplifying that explanation. This is done by ridding it from as much weight as possible that would otherwise tie it to the particularities of the local environment from which it was abstracted. What is gained by ridding the explanation from local specificity is circulation and compatibility with other scientific re-presentations. We can thereby summarise the purpose of circulating reference as the creation of as much distance as possible between an explanation and what it explains, while keeping something constant that maintains the ability to go back and forth between the translations. On the contrary, the modellers in the regulation project sought to decrease distance to what they modelled by applying a diversity of theories that each re-presented idealised elements of the complex phenomena they tried to re-present mathematically. The link between the modellers' work and circulating reference is that the theories they applied in their models can be seen as products of the reductionist process of circulating reference. The purpose of diminishing distance to what the modellers modelled, was to create something that could not only describe a variety of features the target system's behavioural features well enough to predict them, but also eventually to engage operationally with, and become part of the target system to generate a modified behaviour. We can thereby see the modellers to *apply* and combine theory that had already been established through previous amplification and reduction, in order to *prescribe* a system configuration that the modellers believed could adequately generate intended system behaviours of the otherwise incomprehensibly complex phenomena they modelled. Whereas reductionist knowledge production can be understood to reduce complexity and local specificity in order to increase general applicability, the representative modellers instead reduced the general applicability of their model, by increasing its re-presentational complexity, in order to make it speak more specifically of the particular and local they modelled.

Circulating reference/Reductionist science:

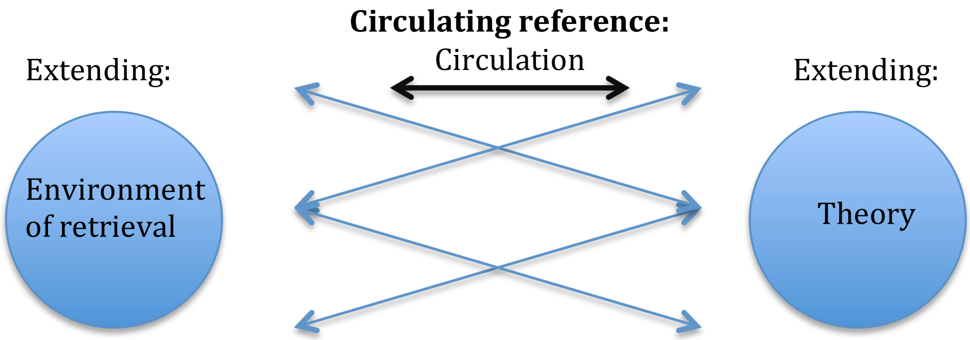


Figure 9.3: Circulating reference: extending both extremes transforming both theory and the environment of retrieval in order to reduce and amplify its re-presentation of the phenomena. Illustration by Author 2013.

Representative modelling in the regulation project:

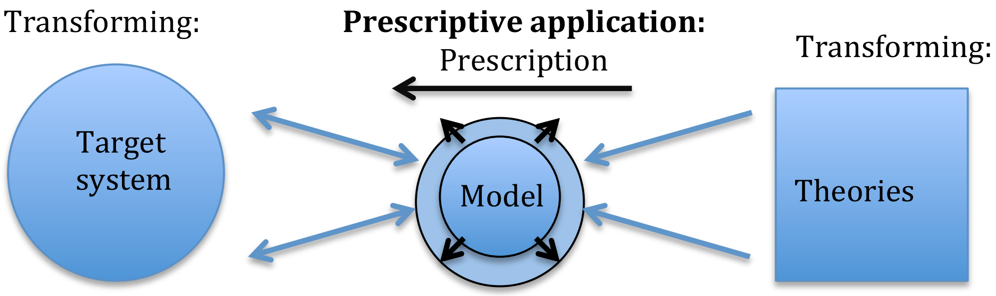


Figure 9.4: Representative modelling as a case of *prescriptive application.* The model is constructed by aligning re-presentations of the target system with those of theories in order to approach the complexities of the target system. Illustration by Author 2013.

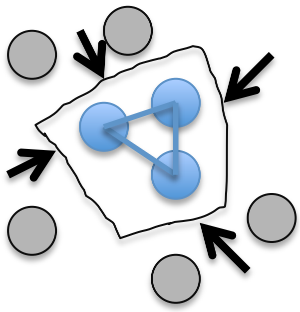
The focused comparison between the representative modelling practice and the reductionist practice of experimental science as presented by circulating reference, hereby produce another illustrative interpretation of their dissimilarities (see figure 9.3 and 9.4). This comparison reveals in greater detail how the model construction can be seen as an entirely different epistemological process that operated by expanding from the middle, with more connections to the extremes, instead of expanding the extremes themselves. The comparison also tells us that the representative modelling included both more explanans and explananda for in this way to reduce distance between the models and their target systems by better approximating the models' re-presentation of the complexity of the particular target systems. If we compare this recognition with the understanding that the models formed the technical content that later were to be integrated as regulation models into the exoteric contexts they re-presented, we can see the purpose of the model's explanatory complexity as an attempt to prepare the models for better operational connection with further exoteric layers of that particular context. In this view we can understand the modellers to include the contexts of the target systems into the very content of the models in order to make their application of theoretical physics into what they believed to be more operational predictions of the system-exostructures they were to form part of and manipulate as regulation models. In this regard we can see the representative models to form *prescriptive* blue prints for the construction of regulated machinations. In order to understand more precisely how we can see this representative model construction to have approached its target system both prescriptively and operationally, the following paragraph will therefore introduce a machine analogy of science that can help us to interpret the model construction as part of a different kind of knowledge machination process than science, that instead applied theory onto the world through what a call *prescriptive application*. This machination metaphor is thereby intended to lay down a stronger bridge between our comprehension of how the models were established as re-presentational content and how they were extended onto become a new operational reality by regulating the production at the factory. The following paragraph is therefore intended to develop a machination metaphor for understanding how the re-presentational reality produced at the theoretical physicists translated onto and transformed the operational reality at the factory.

Machine Analogy of Science

Another way to illustrate the significance of the representative modelling in the regulation project is through Cartwright's machine metaphor, that somehow resembles Latour's concept of circulating reference. In line with Latour, Cartwright argues that science cannot directly understand the world. We therefore need to manipulate the world to make it produce the order we know as physical laws. An arrangement that produces this sort of manipulation is what Cartwright calls a *nomological machine* which is "a fixed (enough) arrangement of components, or factors, with stable (enough) capacities that in the right sort of stable (enough) environment will, with repeated operation, give rise to the kind of regular behaviour that we represent in our scientific laws" (Cartwright 1999, p. 50). Cartwright thereby defines experimental setups as a special kind of machination that enables scientific inquiry by constraining physical objects in certain ways. The point I want to extrapolate from this is that Cartwright's interpretation of experimental science, in contrast to Rheinberger's epistemic-technical dichotomy, can be seen to make the experimental setup's technical function inseparable from its epistemic function. Furthermore, we can also see Cartwright's interpretation to focus on the stabilising function of the experimental machinery as key to its epistemic yields in terms of the physical laws that formed the theoretical basis we saw the modellers to apply. Where Rheinberger's interpretation seems useful for distinguishing between the scientifically interesting known-unknown and the known-known through which it is investigated, Cartwright's interpretation instead explains how experimental machinery stabilises what becomes known as physical laws. This focus on the technical machination as the epistemologically rewarding offers us a metaphor that better enables us to understand how the modellers produced new knowledge through putting together what we can see as a special kind of machines. So what kind of machines are we then dealing with, and how do the machines of the modellers' differ from the nomological machine that Cartwright attributes to the more classical view on science? While the purpose with the nomological machine is to produce ideal conditions for demonstrating scientific laws by technically restricting and delimitating physical phenomena, the purpose of the modellers' machines were on the other hand to produce re-presentational predictions of the complex and non-ideal behaviours of particular machines. The connection between the two types of machines is thereby that the representative modelling built on laws produced by nomological machines. We can thus see the representative modelling as an approach to mathematically project the stabilised contexts produced by nomological machines onto the target machines' unknown interiors at the factory. Because the production machinery did not behave like nomological machines that could be predicted by one single physical law, the mathematical models therefore had to include a combination of different physical laws that together could produce useful approximations of the physical machines' complex behaviour. What is meant by usefulness here is of course strongly depended on the context in which the models were to be used. The point with the machine metaphor is that it enables us to break with the categorical difference between mathematical re-presentations and the production machinery in which they were to become operationalized. We can thus better see the representative models' usefulness in terms of becoming operational parts of regulators that were to steer the production machinery at the factory. For the specific operational purpose at the factory we can thereby identify a number of significant drawbacks related to the way nomological machines are understood to operate, that the modellers had to account for in their construction of their machines. While nomological machines can be seen as central for the formation of the representative models' theoretical content, they would as unreduced physical entities be practically impossible to operationally integrate into the factory's production. Only because they were translated into mathematics could they be inscribed into the regulators' software code as models and thus become operational at the factory. Additionally, we can see the central epistemic function of nomological machines to reduce system behaviour into ideal processes, which made them inadequate for predicting the complex behaviour of the production machinery. In order for the modellers to produce simulated approximations of the production machines' complex behaviour, they therefore needed to first identify what physical laws that they believed could account for different aspects of the production machines' behaviour. In this perspective we can see the modellers' work to resemble that of reverse engineering by first analysing a target machine's parts and their functions –for then to design another machine that can replicate what is deemed as the important aspects of the target machine's behaviour. We can thus see the modellers' reverse engineering to begin when they identified the machines' physical objects and functions. By abstracting these physical functions into mathematized physics the modellers translated the target machines' behaviours into representative models that, in this perspective, were another kind of machine that could produce data simulations of these target machines' behaviours. As machines, we can see these models to consist of mathematical parts that governed their operation. These mathematical parts re-presented the different kinds of nomological behaviours whose combination the modellers believed could be made to adequately simulate the most important features of the machines' behaviour. We can see these theoretical re-presentational choices as the modellers' underlying design of their models. The modellers made these designs by drawing together mathematical arrangements of selected physical laws. We can thus see the theoretical physicists to construct something that had the direct opposite function of nomological machines. The kind of machines that the modellers built were first of all different because they did not produce nomological behaviour from which to abstract mathematized physical laws – such as we understand the function of nomological machines. Instead the modellers' machines were special because they mathematically integrated a combination of physical laws in order to more accurately re-present non-ideal behaviour of a target system. The point with the modelling was thereby to design machinations of physical laws that could make predictions of machines' behaviours that were more useful to the regulation project's operational needs at the factory's production setup. We can thereby see the representative modelling as an approach to compensate for the inadequacy of physical laws to apply to anything but nomological machines.

Figure 9.5 illustrates how the modellers' prescriptive application of physical theories in their modelling deviated from, and compensated for, the reductionist delimitation of what the nomological machines were made to re-present. Where we can see that the nomological machines isolate a few entities from the rest of the world, in order to enable the translation of their isolated behaviour into mathematized physical law, the representative modelling combined such laws in order to expand its explanatory reach to more entities. By this fundamental difference we can understand the purpose of the representative models to re-presentationally approach the complexity of their operational target systems. We can thus see the models to compensate for the esoteric epistemic context of experimental scientific knowledge by combining it in order to better apply to the operational complexity of their exoteric target context.

Nomological machine:
-Experimental science-

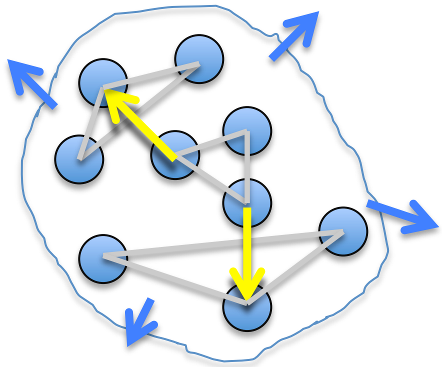


Modus operandi:
Physical manipulation: re-presentational delimitation by isolating elements

Translating the world into theorems by reducing its complexity so that it produce nomological behaviour

The black line signifies the metaphysical boundary between the technically stabilising entities and the stabilised entities of scientific epistemological interest.

Prescriptive application:
-Representative modelling-



Modus operandi:
Mathematical manipulation: re-presentational expansion by inclusion of more than one theorem

Applying theorems onto non-nomological behaviour of the world by increasing re-presentational complexity

The blue line signifies the prescriptive boundary of the machination's reach. Theoretical re-presented entities were incorporated first, later these became operationally connected to physical entities in the production

Figure 9.5: Illustration comparing prescriptive application to Cartwright's nomological machine. Illustration by Author 2013.

Summing up on this chapter's theoretical reflections, inspired by Rheinberger, Latour, and Cartwright respectively, one could say that the regulation project's modelling is characterised by an exoteric epistemology, that built knowledge by emerging the models onto their surroundings by growing more connections between (rather than beyond) given machines and theories, in order to compensate for (rather than delimitating) the complex behaviour of the target environment.

Chapter Ten

Conclusion

Models in Action

To sum up what we have learned from exploring the practices in the regulation project, this concluding section will highlight some of the major recognitions that we can draw from the discussions of the regulation project. For the sake of clarity this will be done in paragraphs that are structured thematically. The order of these themes has been chosen so that we first sum up on the points that address more specifically the regulation project and its organisational context. Then the focus elevates onto what this thesis contribute to the literature on simulation modelling, before lastly concluding what we more generally can learn from this study in terms of our comprehension of science, technology and society.

Techno-Organisational Displacement

The intent with the regulation project from the factory's point of view can largely be classified as a case of technology driven organisational change. As we have seen in the regulation project, technology plays an important role in how organisations work. Another way to understand the relationship between organisation and technology is to see them as so closely intertwined that one cannot be distinguished from the other. It is not only through designing technology that human distinguishes itself from other living forms, but also through designing sophisticated organisations. Technologies can even themselves be understood as outcomes of institutional endeavour (Brown and Duguid, 2001). Mathematical computer models were developed as technological artefacts through the institutional endeavour of the regulation project and became themselves organisational actors when implemented in their operational surroundings. While the models were intended to be technological solutions that liberated the human operators from regulation duties, they instead generated new human tasks and dependences that still relied on the individual operators' engagement with the new technology. In this perspective we saw the regulation project to design technology in order to solve organisational matters, however in doing so, the project largely neglected to engage with the socio-organisational side of the solutions. This became no minor blind spot and while the regulation project's initiatives primarily sought to confine the operators' agency through technology, the same technology showed to depend on the very human agency it was designed to confine.

While technology is understood to both free and constrain the individual (Brown and Duguid, 2001), we can see that human agency in the regulation project became equally responsible for enabling and constraining how the new technology was granted agency. The pursuit for technological fixes to organisational matters did not so much solve or remove these organisational issues as they displaced them from a known state onto a new and unknown one. Instead of setting the operators free, the regulation technology redistributed dependences and thereby created new tensions as these new dependences became institutionalised as new responsibilities. The settlement of these new responsibilities was where the new mathematized solutions evidently themselves became organisational matters. It is this "human" side of the regulation solution that the regulation project did not take as seriously as their technological design on the non-human side of their regulation solution. The declared goal for the regulation project was to produce technological regulation solutions for industrial production. However the analysis shows that the displacement of agency to this new technology consequently lead to novel dependences in terms of the surrounding environment's adaptability to the unforeseen changes it brought. Furthermore the intent of the management to pull control closer to their direct influence resulted in pushing new dependences and risks further away from their influence. The new production setup thereby came to rely heavier on more peripheral variables such as sensors and external technical consultants. We can therefore not talk about technological change as a matter of technical functionality in a limited sense. Instead, we have to grant equally much thought and care to what kind of organisational setup that will best suit the foreseen and unforeseen dependences of a new technological implementation. While technological implementation is of well known importance to engineers and other practitioners who rely on making things that work in practice, the often neglected but equally important dimension to making new things work, is their organisational implementation. However, in order to put this recognition to use it demands us to accept that we cannot distinguish between technological and organisational initiatives and issues as distinct from each other. Where this distinction can be seen as inherited from the modern settlement (Latour, 1991/1993) whereby modernity arose from the idea of separating the human from the non-human, society from nature, and the political from the natural-scientific, the regulation project serves to illustrate why this distinction in fact can set technological and organisational growth at unnecessary risk. However if we on the contrary trace the full range of displacements, the relation between what is considered the domain of technology, and what is considered the domain of organisation, becomes recognisable and thus more tangible to manage in techno-organisational change making. There is a good reason for why workspace designers who engage with displacement of work-environments have to consider all four corners of the *SOFT model: Space, Organisation, Finance, and Technology*. While my argument is that such domains must be perceived as different interpretation of the same displacement, the sensible argument of workspace researchers is that engagement in one corner should entail considerations that cover all four corners (Horgen et al., 1999). Other well-described examples of this phenomenon are the electronic patient journal (Vikkelsøe, 2005), the digital log in, IT education, communication, and planning in the school system and other public institutions. All of these technological endeavours have had significant impacts on the organisation of work and redistribution of dependences in the environments where they were implemented (Vikkelsøe, 2005).

While it was technically possible to displace control and dependences –for instance away from less controllable human variables, the redistribution of dependences and associated risks still relied on the ability of the organisation's information infrastructure to detect unexpected invariances and thus include these in the organisation's control-loops in order to enable the organisation to deal with these invariances as they inevitably will occur. Such a focus is an important part of what I call exoteric assessment because it is about mapping what potential variables that can be thought to affect the realisation of the project. Such an assessment approach stands in stark contrast to the regulation project's, the technical focus on its esoteric closed technical control-thinking that in practice had very little knowledge about the importance of the human operators, which the project generally reduced to be part of the problem rather than also being part of the solution. This disposition caused a less than optimal information feedback because there was no established organisational structure that was responsible for handling these issues. This left much of the potential successes or failures to chance –not careful attention.

Material Performance of Models

While simulation modelling has mostly been explored as a knowledge practice where its particular material affordances have largely been neglected, the regulation project offers a unique contribution to how we can understand models as technological actors that connect knowledge production with operational agency. We can see the range of models in the regulation project, starting with a representative physical model and ending with a regulation model that was integrated into the factory's production, to involve different materialities and thereby different operational complexity. At the black boards the models couldn't do much on their own and were materially very simple, however also easy to manipulate with the touch of a hand. Programmed into computers, the models became much more technical and complicated for the modellers to gain the great advantage of being computable – meaning that they could be crunched into numbers by the computers. At the factory however, the models complexity came to equal that of the machinery they steered. By involving more and more entities as they moved from the blackboards and onto the production, the models and their different operational conditions became more and more complicated –as they thereby became part of a big complicated machination with many new and unexpected uncertainties and risk. This perspective thereby outlines a new interpretation of models that sees them as a special kind of re-presentations that affords us with an analytical framework for exploring how models operate as matter-sign vehicles in different contexts. In the perspective of re-presentations, we can thereby also better recognise how different material states of models connect, and in that way form an infrastructure that exoterically supports the development of the surrounding environment they are part of –such as the regulation project.

Models Beyond Scientific Contexts

What we have recognised from comparing the regulation project to various interpretations of scientific practice, is that the theoretical physicists' modelling does not directly comply to the versions as presented by circulating reference and nomological machines. They resemble neither in terms of their ultimate ends nor in terms of their methodological means. In order to understand the *meaning* and *value* of the modelling we can therefore not project the norms and meanings of traditional science upon its practice. If we for instance consider the reach of the regulation project, in which the physicists' models were entangled and produced various performative effects, it stretched from the practice of the physicists and onto the factory including every part of its great complexity. It is therefore important to recognise that the modelling in the regulation project stretched far beyond the very machine processes it re-presented and generated displacement effects that affected the work of the operators while also introducing new dependences and risks. All of which had to mesh together in order to generate the promised production optimisation potential. The ultimate effects of the regulation project's modelling must therefore be seen to reach far beyond the machines whose behaviours were the objects of their predictions and regulation. For this reason I argue that the demonstrated displacement effect analysis forms a more comprehensible framework for recognising the full extent of modelling effects in techo-scientific endeavours like the regulation project.

Displacement Effects

From the discussion on the displacement effects of the regulation project we saw that its modelling activities only makes partly sense as a knowledge practice. This was further illustrated by comparing the regulation project to the dominant views on scientific knowledge practices. As we have seen, modelling's ability as a knowledge practice to displace ignorance towards new certainty was just one aspect of how it affected the production. When we examined more closely the modelling's material attributes we saw, even more importantly, that it as technological solutions, displaced agency away from the operators and onto its automated machination of the production machinery. While this intended effect of the project can be seen to place modelling onto the organisational scene as a technological solution to a management problem, this effect did not materialise without unintended surprises. For the models' machination of the production machinery to produce their intended effects, their particular implementation relied on the maintenance of its operational conditions. The re-presentational complexity that had originally been designed into them as representative models was now extended to the operational reality of the production. Paradoxically this operational reality included the very human operators whose influence the regulation models were intended to confine. If these human operators did not provide proper maintenance of the new regulation model technology, the promised performance gains of the whole regulation project would be at risk. While the regulation models aspired to displace the human operators' agency, the human operators did not become less important. The displacement of the operators' agency rather had the effect of changing their role from one important area to another, which became the maintenance of appropriate operational conditions for the regulated machines.

Prescriptive Application

In order to draw together what we have learned form the regulation project I propose the notion of *prescriptive application* as a framework for understanding the dynamics of techno-scientific projects like the regulation project and its modelling activities. This concluding paragraph summarises the discussions of this thesis in two figures. The first figure (figure 10.1) compares the context of prescriptive application to that of a classical interpretation of reductionist science. By juxtaposing the significant distinguishing features between these two contexts, figure 10.1 illustrates how prescriptive application provides a radically different framework for understanding events like the regulation project. Prescriptive application thereby offers a framework that is better suited for analysing and interpreting projects that operate beyond science and onto the rest of society by disseminating scientific knowledge through new technological solutions. Figure 10.1 reads like a straightforward comparison between the list belonging to the classical view on science, and the list belonging to what I designate the term: *prescriptive application*. It is important to note that the lists are not mutually exclusive. In fact prescriptive application can be understood as an extension of science. Prescriptive application should thus be read as a displacement of what is obtained through science by extending it onto wider societal contexts.

Context: Characteristic difference:	Scientific practice:	Prescriptive application:
Problems:	Scientific Esoteric 'in here' Epistemic uncertainties	Societal Exoteric 'out there' Risks
Reality:	Re-presentational	Operational
Dimension:	Past	Future
Realisation:	In-folding, closing	Out-folding, opening
Performance:	Scientific claims Amplification	Displacement effects: Agency, Power & New Risks
Meaning:	Kept constant	Out-folding network
Knowledge:	Knowing that	Knowing how
Progression:	Extending extremes further apart Distance	Increasing connections between extremes Proximity
Domain:	Infra-structure	Exostructure
Stability:	Context	Content
Instability:	Content	Context
Sum of variables:	Decreasing Controlled	Increasing Uncontrolled
Assessment methods:	Esoteric validation Scientific reference Truth-value	Exoteric mapping Operational connection Performance
Applicability:	Nomological machines	Particular machines

Figure 10.1: Table comparing traits of the classical conception of scientific practice to the traits of what I term prescriptive application. Illustration by Author, 20113.

Reading figure 10.1 from the top, we first of all see how the nature of problems is displaced when moving from science and onto prescriptive application. Scientific problems are typically of an esoteric in-folding and closing nature being defined from a perspective within a particular scientific discipline. Moving onto prescriptive application we see that problems changes to concern exoteric out-folding, opening, and societal issues instead of esoteric disciplinary issues while at the same time moving from a nature of epistemic uncertainties and onto risks. In the regulation project this was illustrated by moving from the epistemic uncertainty of the representative modelling as it out-folded onto operational risks at the factory. Where science generates claims based on documented past phenomena, predictive application instead generates future displacement effects i.e. displacing agency, power and risks from some entities onto other entities in the machination. Another interesting recognition was that while science is about producing 'knowing that' type of knowledge, prescriptive application comes to depend on the know how that translates the scientific knowing that onto various displacement effects through the machination. We also see a fundamental difference in how science extends its re-presentational extremes further apart creating distance in order to amplify a claim, whereas predictive application instead increases connections between its operational extremes in order to produce proximity and generate effects as part of its target system. We can thus see another important distinction between the infrastructure build by science and the exostructure build by predictive application. Science works by displacing stability from its technical context and onto its epistemic content whereas predictive application operates by displacing stability from its technical content and onto its epistemic context. We thereby also see an important difference in the kind of assessment methods that are applicable. Because science is about delimitating what it studies by decreasing and controlling its number of variables, it generates assessment conditions such as scientific reference, validity and truth-value of its knowledge claim. Predictive application instead increases its number of variables as it out-folds and creates new realities by including additional entities to its machination. Assessment of predictive application can therefore not be validated for its truth-value by going back to documentation of past events and instead relies on mapping potential variables in its future machination. Consequently, science only applies to nomological machines while predictive application instead applies to particular machines or environments.

The second figure (10.2) is intended to illustrate the process of prescriptive application by presenting how it as a machination displaces various features of the knowledge and ideas, from which it originates, onto wider messier applications in the rest of the world. This process is showed as a movement from left to right. Taking heavy inspiration from Latour's depiction of circulating reference, the dynamics of prescriptive application in terms of what is lost in order to gain something else, is signified as two overlaying opposite triangles. One decreases from left to right to indicate what qualities are lost when scientific knowledge is prescriptively applied onto the messy, unpredictable, and complex world. The other triangle increases from left to right and denotes what qualities that are gained when knowledge is prescriptively applied and extended as solutions onto practical problems in the world. It is important to note that this figure presents the dynamical relationship between prescriptive application and science by illustrating the fundamental principle behind the displacement of effects that are associated with applying scientific knowledge beyond the restrictions of a scientific context. Figure 10.2 thereby illustrates how scientific knowledge is displaced onto the rest of the world by highlighting characteristic features of scientific knowledge in the left list and what they are displaced onto, in the right list of features. The point is thereby not to compare science and prescriptive application, which was the purpose of the previous figure, but rather to illustrate the dynamics of how prescriptive application out-folds by trading away some qualities in order to gain others.

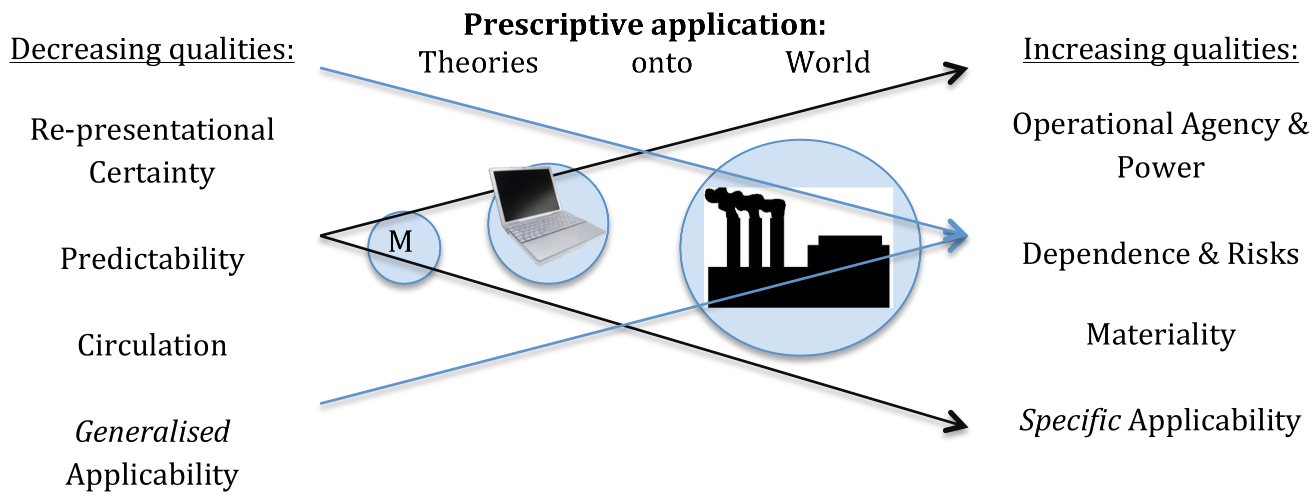


Figure 10.2: Illustration of the displacement of features when scientific knowledge is prescriptively applied onto other societal contexts. Illustration by Author 2013.

Prescriptive application can hereby be seen as a suggestion for an alternative context interpretation that more adequately offers a meaningful framework for understanding the complicated and intertwined displacement effects we have encountered in the regulation project. While there exists many interpretations of what scientific practice is about, prescriptive application is instead intended as a proposal for understanding something that is much messier, is more complex, and have even more facets than we know of science. Prescriptive application therefore needs to be understood, not as what something is about, but rather as a perspective on something to become. For that reason it is important to read my proposed framework as an alternative suggestion that is as open for interpretation and deformation as what the particularities of other potential cases might demand. The fundamental principle however stands; opposed to the classical interpretation of science, prescriptive application is about the displacement from something abstracted, closing, esoteric, controlled, and predictable that has *generalised* applicability, onto the concrete, opening, exoteric, uncontrolled, and unpredictable that develops into *specific* applications. While circulating reference described the translation of the world into words, prescriptive application designates the reverse process –the use of language to transform the world. Whereas science have been recognised to be produced under particular, historical, social, and material circumstances, its ultimate goal has still been to produce knowledge that could ultimately, however unlikely, become disentangled from its conditional ties. Prescriptive application on the other hand does not share ends with science; prescriptive application is all about its ties to particular, individual, social, material and historical settings, because these are not its conditions as much as they are its substance. By encompassing scientific knowledge production as well as science's wider effects through how it technologizes society, prescriptive application can be seen as an extension of Jasanoff's (1996) "full-blown political analysis of science and technology [that] seeks to illuminate the 'co-production' of scientific and social order –that is, the production of mutually supporting forms of knowledge and forms of life" (pp. 397). The prescriptive application framework thereby offers a more thorough analytical connection between what has been designated under the broad and often confusing notion of 'design' and studies on science, technology and society. Schön's (1987) definition illustrates some of designing's important resonances with the proposed framework for prescriptive application: "Designing, in its broader sense involves complexity and synthesis. In contrast to analysts or critics, designers put things together and bring new things into being, dealing in the process with many variables and constraints, some initially known and some discovered through designing. Almost always, designers' moves have consequences other than those intended for them." (pp. 41-42). We can thus see prescriptive application to share some central contrasting features to scientific analysis and critique as those Schön denotes to design. Prescriptive application however provides us with a new comprehension of how we can see both the connections, and the distinctions, between scientific practices and practices that translate abstract theoretical knowledge onto broader societal displacement effects. Unlike design that by definition excludes scientific analysis (Schön, 1987), and seldom is denoted to distribution and implementation, prescriptive application includes esoteric analytical outputs as its inputs and never stops out-folding onto additional layers of the exostructure it is becoming. It extends as a network and knows nothing of negation, only of operational connection. It extends until something else beats it on its own terms, which are those of applicability and exoteric impact. Framed by Jasanoff's (2012) critique of the laboratory studies' delimitated focus on scientific controversy, we can see prescriptive application an extension of the script tracing ANT methodology onto societal matters of concern. However, while Jasanoff draws on Giere's (1989) credit to Nelkin's (1971) *controversy* to spell out a focus on "social controversies as laboratories for studying how science and technology work in society" (Jasanoff, 2012: 439), prescriptive application instead places weight on another metaphor that seems more adequate for describing the event that has been studied in this thesis. Because laboratories are known to build esoteric, controlled, and closed arrangements in order to produce facts about delimitated and controlled phenomena, prescriptive application instead suggests to leave facts at their right place –in the laboratories; to instead scale our focus onto the production of entirely different kinds of products that can better capture the surrounding society's matters of concern, than what can be designated to machinations that produce scientific facts alone. In this view we can see the *machination* metaphor to offer a more open-ended and question generating interpretation of what kind of products that can describe, and make prescriptive application effects, more tangible. Facts have their justification and place in the purpose built factories we call laboratories, through which they have been constructed. Prescriptive application instead produces effects that have yet to manifest themselves through the uncontrollable and unpredictable environment we call society of tomorrow. What can be seen, as an inferior product in the epistemological frame of a laboratory, can become an effective product in the operational frame of society – and vice versa.

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ABSTRACT

Models in action – realising abstractions

This thesis is about mathematical modelling and technology development. While mathematical modelling has become widely deployed within a broad range of scientific practices, it has also gained a central position within technology development. The intersection of mathematical modelling and technology development is especially interesting because of its increasing role in applying scientific theoretical knowledge to concrete societal problems, and even more so, because it is a relatively little studied practice. Based on a multi-sited ethnographic study of an industrial energy-efficiency project, this thesis presents an analysis of the central practices that materialised representative physical modelling and implemented operational regulation models. In order to show how the project's representative modelling and technology development connected physical theory with concrete problems through different material mediations, the thesis draws on the notion of re-presentation as used within science and technology studies to trace how the project translated between the various states of re-presentative mediations.

The first four chapters introduce the scope of the study and its wider theoretical outset, the existing literature on simulation models, and the study's methodological and empirical approach. The purpose of this thesis is to describe the central practices that developed regulation technology for industrial production processes and to analyse how mathematical modelling contributed to this development. Because the variation between these practices spanned from work with physical theory to practical hands-on work with machines at operational production sites, the thesis aims to capture how these diverse practices operated and connected by closely following how they transformed and distributed knowledge artefacts.

Chapter 5 to 7 unfolds the empirical study structured as an investigation of two opposite processes that occurred simultaneously; one that "abstracted" the production machinery into theoretical physics (Chapter 5 and 6), and one that "concretised" theories onto the production machinery (Chapter 7). Mathematical models are especially interesting in this technology developing setup since they formed a significant part of both the processes that abstracted machinery and the processes that concretised theory and filled an important role in the coordination between these two opposite processes. By following each stage in both opposite processes, I seek to extend the existing comprehension of models' technological and epistemological dimensions by describing the different material states the models went through from machine to theory and back again to the machine.

Chapter 8 analyses and discusses the different effects that were generated by implementing the regulation model technology onto their target environments. The thesis results in a discussion of what kinds of displacement effects these novel technological solutions can be recognised to have generated. Structured around the intersections of certainty, agency, and dependences, the thesis' findings are in chapter 9 extended to a discussion of the theoretical fundament through which we interpret the regulation project and its use of modelling. I demonstrate a novel framework that I term *prescriptive application*. Chapter 10 summarises and concludes on the recognitions that are drawn from the study.

Dansk resumé

Modeller i Aktion – realisering af abstraktioner

Denne afhandling handler om matematiske modeller og teknologisk udvikling. Mens matematisk modellering har nået stor udbredelse indenfor videnskabelige praksisser, har modellering også opnået en central position indenfor teknologiudvikling. Krydsfeltet mellem matematisk modellering og teknologiudvikling er særligt interessant fordi det forbinder videnskabelig viden med problemer i samfundet, og i endnu højere grad fordi den udgør er en relativt lidt studeret praksis. Denne afhandling er baseret på et multi-sited etnografisk studie af et industrielt energi-effektivisings projekt og præsenterer en analyse de centrale praksisser der materialiserede repræsentativ fysisk modellering og implementering af operationelle regulerings modeller. Med henblik på at kunne vise hvordan projektets repræsentative modellering og teknologiudvikling koblede fysisk teori og konkrete problemer gennem forskellige materielle mediationer, trækker denne afhandling på begrebet re-præsentation som er brugt indenfor videnskabs og teknologi studier for at spore hvordan projektet oversatte mellem de forskellige stadier af re-præsentative mediationer.

De første fire kapitler introducerer studiets formål og dets bredere teoretiske udgangspunkt, den eksisterende litteratur om simulations modeller samt studiets metodologiske og empiriske tilgang. Formålet med afhandlingen er at beskrive de centrale praksisser der udviklede industriel reguleringsteknologi og at analysere hvordan matematisk modellering bidrog hertil. Grundet forskelligheden mellem arbejdet med fysisk teori og arbejdet med fysiske maskiner i operationelle produktioner, er denne afhandlings formål at beskrive hvordan disse forskellige praksisser operarede kobledes ved at følge hvordan de omformede og distribuerede videns artefakter.

Kapitel 5 til 7 udfolder the empiriske studie struktureret som en undersøgelse af to modsatrettede simultane processer; en der ”abstraherede” produktionsmaskineriet til teoretisk fysisk (kapitel 5 og 6), og en der ”konkretiserede” teorier på produktionsmaskineriet (kapitel 7). Matematiske modeller er særligt interessante dette teknologiudviklings set up eftersom de udgjorde en væsentlig andel af både de processer der abstraherede maskiner og de processer der konkretiserede teori og udfyldte en vigtig rolle i koordinationen mellem disse to modsatrettede praksisser. Ved at følge hvert stadie i begge disse modsatrettede processer, søger jeg at strække den eksisterende forståelse af modellers teknologiske og epistemologiske dimension ved at beskrive de forskellige materielle stadier modellerne gennemgik fra maskine til teori og tilbage til maskinen.

Kapitel 8 analyserer og diskuterer de forskellige effekter der blev genereret gennem implementeringen af reguleringsmodellerne i deres tilsigtede miljøer. Afhandlingen resulterer i en diskussion af hvilke typer af forskydningseffekter disse nye teknologiske løsninger kan forstås at have genereret. Struktureret omkring skæringspunktet mellem vished, handlen og afhængigheder, er afhandlingens resultater i kapitel 9 forlænget til diskussionen af det teoretiske fundament gennem hvilket vi kan tolke reguleringsprojektet og dets anvendelse af modellering. Jeg demonstrerer en ny fortolkningsramme som jeg kalder *præskriptiv applikation.* Kapitel 10 opsummerer og konkluderer på studiets erkendelser.

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2. Joakim Juhl
3. Professor (MSO) Torben Elgaard Jensen
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